ANL/ESD-18/2

Employment Effects of Hydrogen and Fuel Cells: Phase 1 Report, Fuel Cell Electric Vehicles

Energy Systems Division

ANL/ESD-18/2

Employment Effects of Hydrogen and Fuel Cells: Phase 1 Report, Fuel Cell Electric Vehicles

by
Marianne Mintz
Energy Systems Division, Argonne National Laboratory

Catherine Mertes
Eric Stewart
Stephanie Burr
RCF Economic & Financial Consulting, Inc.

January 2018

CONTENTS

CONTENTS (CONT.)

FIGURES

FIGURES (CONT.)

FIGURES (CONT.)

TABLES

TABLES (CONT.)

NOTATION

AEO-2016	*Annual Energy Outlook 2016*
bbl	barrel
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
BoP	balance of plant
Btu	British thermal unit(s)
CaFCP	California Fuel Cell Partnership
CAGR	compound annual growth rate
CARB	California Air Resources Board
CO_2	carbon dioxide
(U.S.) DOE	(United States) Department of Energy
(U.S.) EIA	(United States) Energy Information Administration
(U.S.) EPA	(United States) Environmental Protection Agency
FC	fuel cell
FCEV	fuel cell electric vehicle
FCTO	Fuel Cell Technologies Office
GHG	greenhouse gas
GPRA	Government Performance and Results Act, Public Law 103–62
GREET	Greenhouse Gases, Regulated Emissions, and Energy in Transportation model
H_2	hydrogen
HFI	Hydrogen Fuel Initiative
ICE	internal combustion engine
ICEV	internal combustion engine vehicle
LCFS	Low Carbon Fuel Standard
LDV	light-duty vehicle
MDS	manufacturing, distribution and sales
Mpgge	miles per gal gasoline equivalent
NAICS	North America Industry Classification System
O&M	operation and maintenance
OEM	original equipment manufacturer

PHEV	plug-in hybrid electric vehicle
psi	pounds per square inch
RCF	RCF Economic & Financial Consulting, Inc.
REMI	Regional Economic Models, Inc.
RPE	retail price equivalent
RPC	regional purchase coefficient
STEM	Science, Technology, Engineering, Mathematics
SUV	sport utility vehicle
tpd	tons per day
ZEV	zero emission vehicle

ACKNOWLEDGMENTS

REVIEWERS

David L. Greene, Baker Center for Public Policy, University of Tennessee
Michael Q. Wang, Energy Systems Division, Argonne National Laboratory
Fred Treyz, Regional Economic Models, Inc.

SPONSOR

This work was sponsored by the U.S. Department of Energy's Fuel Cell Technologies Office.

AUTHOR DISCLAIMER

EXECUTIVE SUMMARY

This report describes employment impacts associated with the manufacture, distribution and sale (MDS) of light-duty fuel cell electric vehicles (FCEVs) under a mid-range scenario of market development and uptake. Termed "gross" employment, these estimates include direct and indirect, full-time and part-time jobs associated with manufacturing, distributing and selling FCEVs, but not the consequent reduction in employment resulting from reduced demand for conventional vehicles (i.e., displaced employment). The latter estimates are included in a forthcoming technical memorandum documenting Phase 2 of this study.

This report was prepared by staff of Argonne National Laboratory and RCF Economic and Financial Consulting, Inc. for the U.S. Department of Energy's (DOE's) Fuel Cell Technologies Office (FCTO). In earlier work, Argonne and RCF analyzed employment impacts associated with a large-scale transition to hydrogen and fuel cells. The earlier work formed the basis for a 2008 DOE Report to Congress, which this effort updates and expands.

Unlike the Report to Congress, which examined effects of a supply-side focused Hydrogen Fuel Initiative under which nearly all light-duty vehicles (LDVs) transition to hydrogen, the current effort required development of a new, mid-level scenario of market development, largely focused on the demand side. In order to leverage existing DOE-supported tools and studies, several ongoing efforts informed the process used to develop that scenario, which has been named the Multi-Market Scenario. These other efforts included modeling associated with EIA's Annual Energy Outlook, H_2USA's analyses of proposed H_2 station rollout scenarios and FCTO's benefits assessment of the hydrogen and fuel cell program. The resulting Multi-Market Scenario includes separate market penetration forecasts for five U.S. regions with different regional economies as well as existing policy support for FCEVs. Thus, while market penetration under the scenario exceeds a third of all LDV sales in the western and northeastern parts of the U.S. in 2050, overall penetration is considerably less. By 2050, FCEVs capture roughly 20% of national LDV sales and account for roughly 10% of all LDVS on the road in the U.S.

Estimates and assumptions developed in support of the Multi-Market Scenario provided the basis for adjusting and/or creating new industrial sectors in REMI, the macroeconomic model chosen for this analysis. These changes reflect adaptation within the U.S. economy to changing demand and supply chains. Four additional sectors were constructed (FC stack, FC system, FC car, FC light truck) using data from related industries, the U.S. National Input and Product Accounts and the U.S. Censuses of Manufacturing, Wholesale and Retail Trade, and Construction. Two variants of the Multi-Market Scenario were examined, one in which FCEV production reflects the current split between domestic and foreign assembly of all LDVs sold in the U.S., and another in which production reflects the current split between domestic and foreign assembly of plug-in hybrid electric vehicles sold in the United States.

As shown in Figure ES-1, roughly 120,000 gross supply-chain jobs are associated with the *manufacture* of FCEVs in 2050. Most of these jobs are concentrated in states with dense manufacturing supply chains, primarily in the Central Industrial region of the U.S. The number of manufacturing jobs is very sensitive to domestic versus foreign assembly, with results varying from approximately 80,000 gross supply-chain jobs if FCEV assembly mirrors current patterns for all LDVs sold in the U.S. to over 160,000 gross supply-chain jobs if a greater share of assembly occurs in the U.S. Note that "manufacturing" jobs include not only direct employment in FC stack, system, and FCEV fabrication and assembly, but also "white collar" and supporting service employment throughout the supply chain.

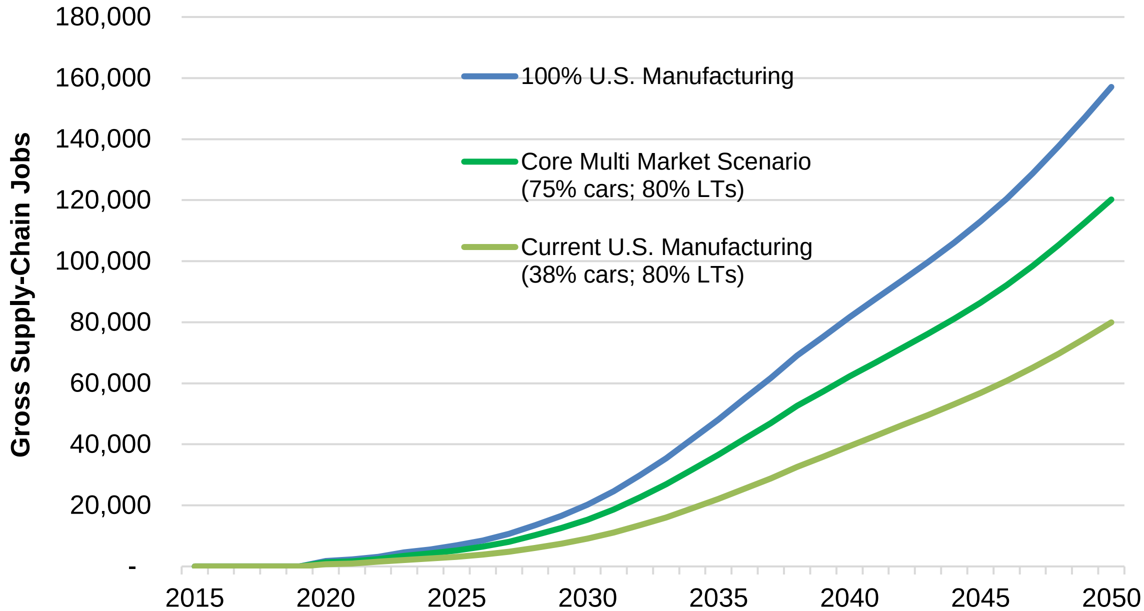

FIGURE ES-1 Gross Supply-Chain Jobs Associated with FCEV Manufacturing under Alternative Location Assumptions

Unlike manufacturing, jobs associated with FC *distribution and sales* tend to be located in regions where FCEV demand is greatest. By 2050 nearly 200,000 gross jobs in distribution/sales are associated with FCEV activities under the Multi-Market Scenario. Most of these jobs are in retail sales and they are distributed in all regions.

Figure ES-2 shows *total* gross employment associated with the Multi-Market Scenario by region. Initially, growth is strongest in the Western region in response to ongoing efforts to achieve clean fuel targets. However, since the Multi-Market Scenario assumes that states achieve their deployment targets and that regions retain their historic manufacturing supply base and shares of national LDV sales, regions with (currently) lower levels of policy support for FCEVs begin to see gains in gross employment associated with the MSD of FCEVs that equal or exceed those in regions with strong policy support. Thus, by 2050 all regions gain significant shares of the over 300,000 gross jobs associated with FCEV penetration in the Multi-Market Scenario. Under the Multi-Market Scenario, FCEV market penetration (and associated growth in FCEV manufacturing, distribution and sales employment) rises especially fast in the Central Industrial and Rest of U.S. regions toward the end of the study period. As a result, not only are significant numbers of jobs created across a broad range of industries and occupations, but jobs are growing at an increasing rate, suggesting a continuation well beyond 2050.

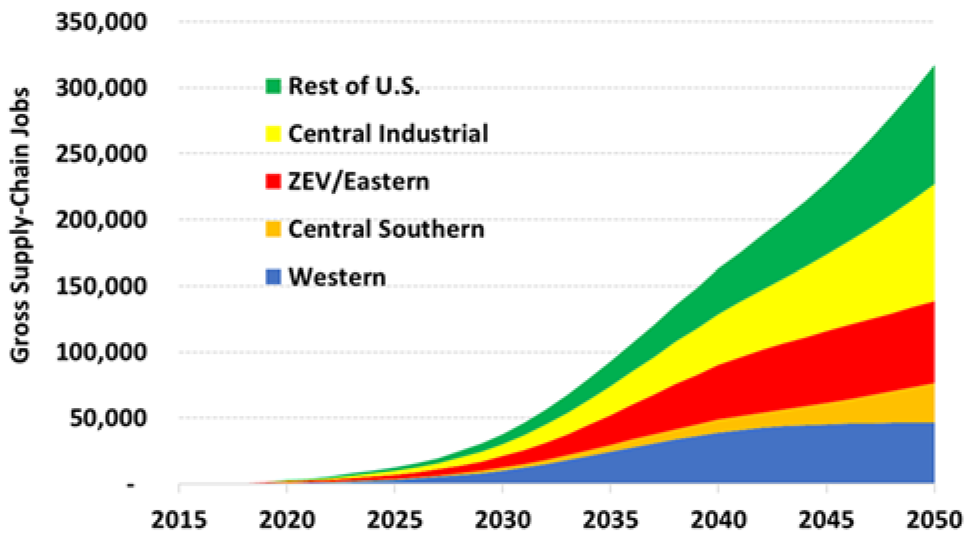

FIGURE ES-2 Gross Supply-Chain Jobs Associated with FCEV Manufacturing, Distribution and Sale, Multi-Market Scenario

1 INTRODUCTION

1.1 CONTEXT AND RELEVANCE

This report updates and expands upon the U.S. Department of Energy's (DOE) 2008 Report to Congress. Authorized by the 2005 Energy Policy Act (PL109-58), that report (*Effects of a Transition to a Hydrogen Economy on Employment in the United States)* documented "a study of the likely effects of a transition to a hydrogen economy on overall employment in the United States… (including replacement effects, workforce training requirements, regional variations, etc.)…" The study combined the twin goals of energy independence and a transition to clean energy sources as expressed in President Bush's 2003 Hydrogen Fuel Initiative (HFI):

> *"With a new national commitment, our scientists and engineers will overcome obstacles to taking (fuel cell) cars from laboratory to showroom so that the first car driven by a child born today could be powered by hydrogen, and (be) pollution-free. Join me in this important innovation to make our air significantly cleaner, and our country much less dependent on foreign sources of energy."* (Bush 2003)

Effects of a Transition to a Hydrogen Economy on Employment in the United States reflected 2003─2008 levels of technology advancement and anticipated fuel prices, economic activity and market success. As shown in Figure 1, world oil price rose steadily over that period, peaking at $143.95/barrel (bbl) on July 3, 2008.[1] Since 2015, however, oil price has dropped closer to its 1988−2004 range.

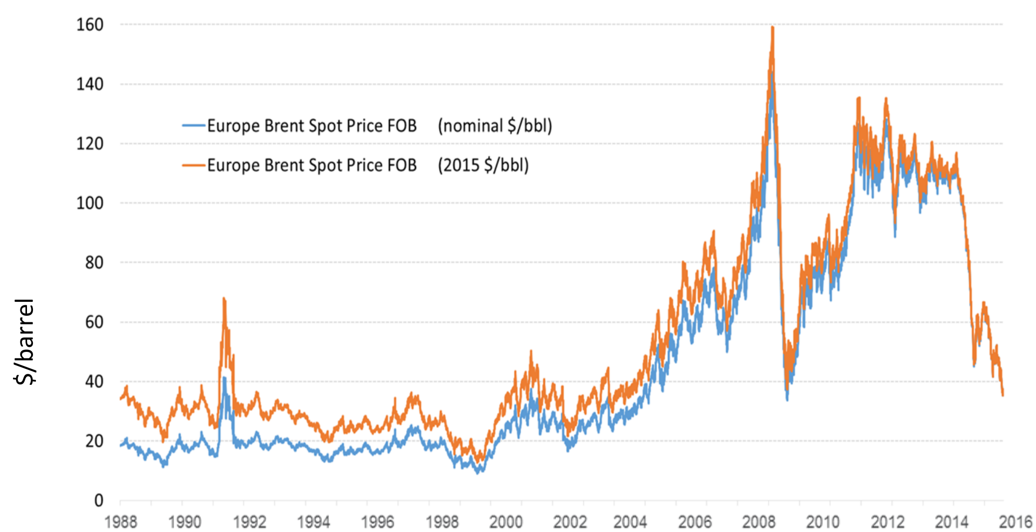

FIGURE 1 World Oil Price, 1988−2016

[1] The Report to Congress was issued in July 2008.

In addition to oil price, several other key parameters have changed markedly since 2008:

- Hydraulic fracturing has opened up vast reserves of shale oil and gas to commercial development, reducing U.S. oil imports from over 65% of supply in 2008 to less than 25% today. The associated decline in OPEC market power has depressed *world oil price* and contributed to the view that energy prices are unlikely to spike in the near term.

- *New emission standards* for light-duty-vehicles (LDVs) have been enacted, requiring significant increases in fuel economy, and/or shifts in engine technologies.

- California has re-doubled its *push toward zero emission vehicles* (ZEVs) and implemented a *Low Carbon Fuel Standard* (LCFS) to reduce the carbon content of fuels consumed in that state. Oregon has adopted a similar standard and eight other states have committed to promoting ZEVs and various levels of greenhouse gas reduction.

- *Fuel cell (FC) costs have declined* steadily. Systems have entered early markets including lift trucks, portable power and backup/emergency power and three original equipment manufacturers (OEMs) have begun selling or leasing FCEVs[2] in California, with plans for expansion into select markets in the Northeastern U.S. and Hawaii.

- *Increasing numbers of ZEVs are on the road* in the form of battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and FCEVs.

Thus, many of the assumptions surrounding the HFI, and by extension the study documented in the Report to Congress, are in need of revision. That is the intent of this report.

1.2 RELATIONSHIP TO THE 2008 REPORT TO CONGRESS

In addition to updating assumptions to reflect 2017 conditions, this report expands upon the 2008 analysis in several ways.

- Regional analyses are conducted for five portions of the country which together comprise the entire U.S. Since the same scope and methodology is applied to each region, regional results can be summed to equal total U.S. results. In the 2008 study select regions of different sizes were examined in separate off-line analyses and results could not be compared across regions.

- Implications of scenario results on workforce development are a direct output of this analysis. Our economic modeling estimates employment impacts by industry and occupation, thereby permitting results to be summarized in multiple ways. In the 2008 study, a separate off-line analysis was conducted to investigate the types of jobs likely to be affected and potential education/training requirements associated with those types of jobs.

[2] Current FCEV models include Toyota Mirai, Honda Clarity and Hyundai Tucsan.

1.3 REPORTING

This report focuses on employment associated with the manufacturing, distribution and sale (MDS) of FCEVs. It documents the methodology, key assumptions and major findings of our analysis of gross additions to employment resulting from FCEVs. A technical memo focusing on MDS of the H_2 required to support those FCEVs will be issued in early 2018. That document will provide estimates of gross employment impacts associated with H_2, along with estimates of displaced jobs (due to reduced demand for gasoline and gasoline-powered vehicles) and net effects (i.e., gross jobs – displaced jobs) from H_2 and FCEV development in the Multi-Market Scenario.

1.4 ORGANIZATION OF THIS REPORT

Following the Executive Summary and this introduction, the report is organized into six additional sections or chapters:

- Section 2 describes the scenarios around which the analysis is centered, their relationship to other ongoing DOE-supported efforts and tools, and the input assumptions they provided for economic modeling.
- Section 3 discusses macroeconomic modeling in general, as applied in this study, and in terms of the specific inputs developed to examine the economic impacts of FCEVs.
- Sections 4 and 5 present results, both for the U.S. as a whole (Section 4) and for the five regions examined (Section 5).
- Section 6 discusses alternative scenarios related to the location of FCEV manufacturing.
- Section 7 presents a summary of results and initial conclusions.
- Appendices A−D provide additional detail on data sources, assumptions and intermediate calculations.

2 SCENARIOS INTEGRATING FUEL CELLS IN THE U.S. ECONOMY

As discussed in Section 1, the HFI provided an aspirational scenario which underlies the analyses in DOE's 2008 Report to Congress. Today, there is no comparable scenario reflecting national goals. There are, however, scenarios associated with specific efforts, for example H_2USA, H2@Scale, the deployment of H_2 infrastructure pursuant to ZEV goals in California and the Northeast, the Energy Information Administration's (EIA's) Annual Energy Outlook (AEO), and DOE's analyses of program benefits in conjunction with the Government Performance and Reporting Act (GPRA Stephens et al. 2017a). To the extent possible, this project utilized these efforts and the tools developed to support them in order to develop a reference scenario. Since many of these efforts were concurrent with ours, our reference scenario is not exactly the same as any one scenario embodied in those efforts. It is, however, informed by those efforts and thus *consistent with a middle level of market penetration assuming success in achieving DOE's performance and cost targets for H_2 and FC systems.*[3]

In addition to specifying a reference scenario, this analysis also required specification of a base scenario from which changes could be computed and regional scenarios for which regional impacts could be identified. The base scenario is a generic "no program" case which is specified for each region as well as for the country as a whole (see Sections 2.3 and 3.3). Regional versions of the reference scenario reflect the different economic and environmental concerns of each region which may be expected to affect the degree and speed of uptake of new technologies like FCEVs. These are discussed in Section 2.1 and in Section 5, as well as in Appendix A.

Several tools and efforts supported by DOE's Fuel Cell Technologies Office (FCTO) and Vehicle Technologies Office (VTO) were used to expand EIA's 2016 Annual Energy Outlook (AEO-2016) Reference Case for vehicle sales and energy prices, tailor it to the five regions shown in Figure 2, and add the anticipated cost and market performance of fuel cell technologies under a successful FCTO program. These tools include models like Autonomie (which provides estimates of vehicle and component costs over time); MA3T, ParaChoice and Lave-TRANS (Stephens et al. 2017b) which provide estimates of market shares for FCEVs consistent with FCTO's analysis for GPRA; and VISION (which translates regional estimates of FCEV and conventional vehicle sales into estimates of vehicle stocks and fuel use for each of the five regions). Other efforts that informed the scenario development process include findings from the H_2USA Locations Roadmap Working Group and FCTO's Fuel Cell System Cost Analyses. Thus, our reference scenario reflects key assumptions and methodologies not only from AEO-2016, but also from several related FCTO-affiliated tools and efforts. Because our reference scenario focuses on markets for FCEVs and the H_2 to support them, we have named it the Multi-Market Scenario.

---

[3] Note that the scenarios used in this study were developed in late 2016 and preliminary results were reported at FCTO's 2017 Annual Merit Review (Mintz and Mertes 2017). Thus, several parameters had to be finalized before these other efforts were concluded and thus do not reflect final adjustments/revisions in their model results.

2.1 NATIONAL AND REGIONAL SCENARIOS

Like other new technologies, FCEVs are likely to achieve greater market success, at least initially, in regions where they offer greater benefit to consumers. The macroeconomic model selected for this analysis is particularly well suited to identify these impacts. However, regionalization is a two-edged sword. While producing *n* sets of results (where *n* is the number of regions), regionalization requires *n* separate models with *n* sets of inputs. Thus, a balance must be struck between available resources and desired detail. For this analysis, that balance is the five regions shown in Figure 2. These were selected to represent a diverse set of economic and policy conditions including policies promoting ZEVs (Western and ZEV/Eastern regions), a historically strong automotive manufacturing base (Central Industrial region), and growing automotive supply chains (Central Southern region). To avoid repetition, each regional scenario is not discussed separately here. Rather, key differences are highlighted as appropriate.

FIGURE 2 Analysis Regions for this Study

2.2 MULTI-MARKET SCENARIO: DEVELOPMENT AND FEATURES

The Multi-Market Scenario reflects achievement of FCTO's technology and cost targets in the context of EIA's AEO-2016 Reference Case forecasts of energy prices and economic activity. As fuel cells and hydrogen become increasingly competitive, FCEVs gain market share in multiple markets. Favorable policies provide an initial push in infrastructure development facilitating early market development first in California, then in other states with ZEV mandates, and finally in states without such policy incentives. Thus, FCEV market penetration varies significantly across regions.

As with ZEV policies adopted by California, the Pacific Northwest and several Northeastern states, the Multi-Market Scenario focuses initially on light-duty vehicles (LDVs). Termed the "core" market, LDVs are the largest potential market for FCs and thus are the initial focus of our analysis of market penetration, utilization and hydrogen production and use. Other portions of the Multi-Market Scenario (which may be addressed in subsequent phases of our analysis) include medium- and heavy-duty trucks and buses, materials handling equipment, and stationary fuel cells in applications like prime and backup power. As with the core market, employment impacts associated with these other markets within the Multi-Market Scenario can be estimated by region, industry and occupation. Figure 3 depicts the relationship between the core and other markets of the scenario, along with H_2 production and delivery which support all these markets. As stated earlier, H_2 production and delivery are not included in this report.

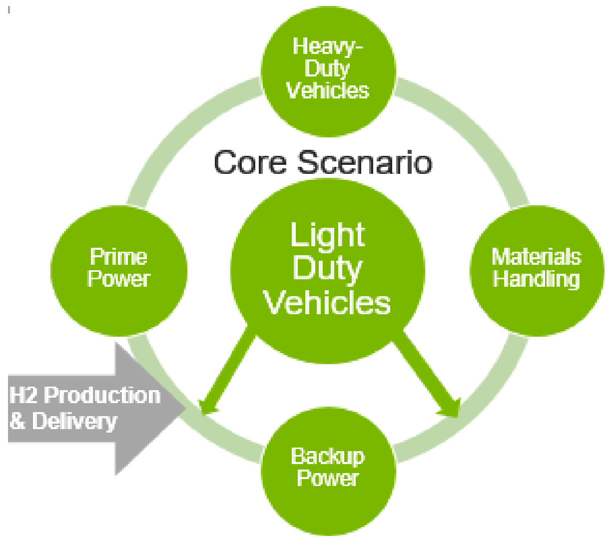

FIGURE 3 Multi-Market and Core Multi-Market Scenarios

2.2.1 FCEV Market Penetration

As discussed above, the Core Multi-Market Scenario was constructed with DOE-supported tools and intended to align with other FCTO-supported efforts. For estimating FCEV market penetration the key ongoing effort is FCTO's GPRA analysis. In that work, four market penetration models[4] were used to estimate FCEV market success. Each model was provided with the same input assumptions — for FCEV and conventional vehicle characteristics, infrastructure availability and fuel/energy prices — and model developers generated independent estimates of market shares by vehicle size/type and technology. Preliminary results show wide variations in FCEV market shares in terms of both their trajectory over time and their end-year magnitude (6−42% of car sales and 6−37% of light truck sales in 2050). Because of these variations, no single model result was considered representative (and thus a good candidate for FCEV market penetration) when our Core Multi-Market Scenario was being developed. However, there was considerably more agreement in preliminary estimates of electric drive (i.e., PHEV + FCEV) market shares (66−74% of car and 61−67% of light truck sales in 2050). Assuming FCEVs

[4] These models are ParaChoice, developed by Sandia National Laboratory, Lave-TRANS and MA3T developed by Oak Ridge National Laboratory and LVCFlex developed by Energetics, Inc.

account for half of these shares in regions with strong policy support, market penetration could reach 35% of car and 32.5% of light truck sales in Western and ZEV/Eastern regions in 2050.

Using this target market share for the Western region, along with California's estimates of annual FCEV sales through 2022 (CARB 2016), a logistic market penetration curve was estimated for the entire Western region. A similar curve was estimated for the ZEV/Eastern region using H_2USA assumptions for market entry (i.e., a five-year delay) and comparable overall success. Shares for all other regions were estimated to reflect a ten-year delay from ZEV/Eastern market entry and a similar market penetration trajectory, but without any ultimate target.[5] Figures 4 and 5 show the resulting market penetration assumptions for cars and light trucks, respectively, in all regions. Note that in both figures the green line corresponding to the "Rest of U.S." overlays comparable lines for the Central Industrial and Central Southern Regions indicating the *same rate of market penetration across all three regions*.

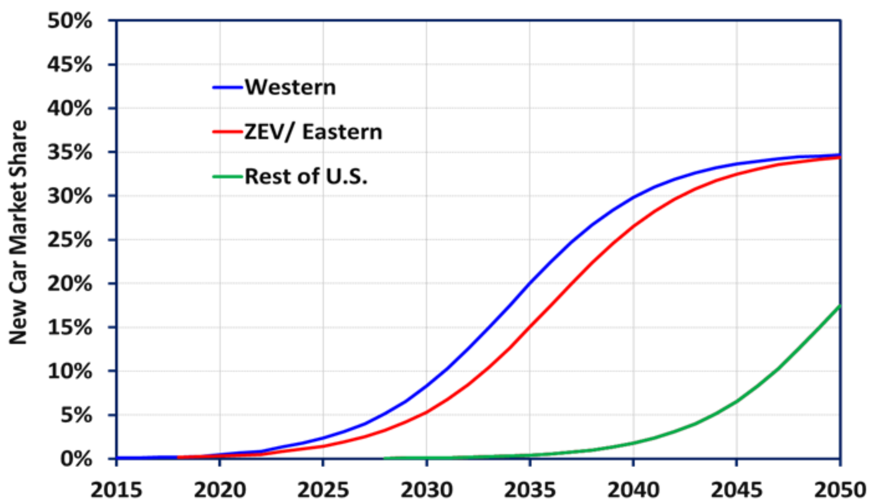

FIGURE 4 FCEV Car Market Penetration, Core Multi-Market Scenario

[5] See Appendix A for additional discussion of the process used to derive regional market penetration forecasts.

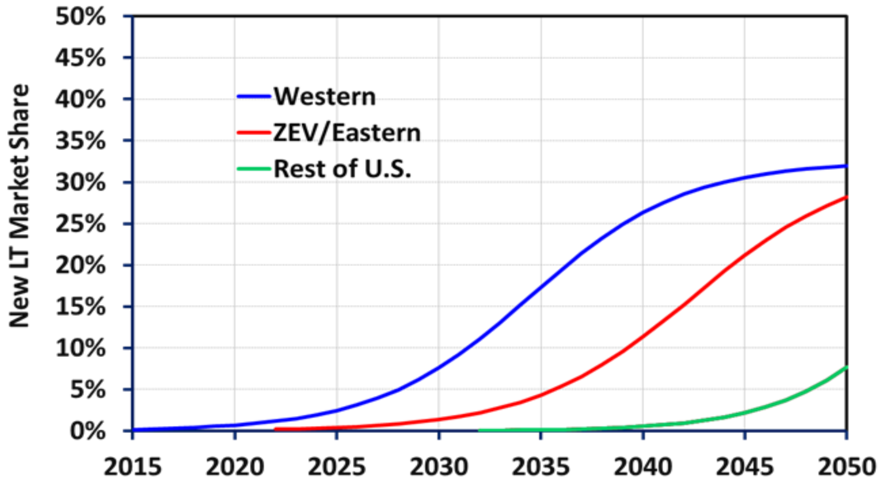

FIGURE 5 FCEV Light Truck Market Penetration, Core Multi-Market Scenario

2.2.2 Sales of FCEVs by Region

In the Multi-Market Scenario, FCEV car and light truck sales by year and region are a function of national LDV sales, the distribution of those sales by region, the split between cars and light trucks in each region and FCEV market penetration by region. In the AEO-2016, the EIA forecasts car and light truck sales by census region. Using historical relationships and population forecasts from the U.S. Department of Commerce's Census Bureau, we disaggregated EIA's forecasts and our regional FCEV market penetration assumptions to the state level from 2015 through 2050. Then, we aggregated the state-level estimates to our five regions for input to the VISION model. Figures 6 and 7 display the resulting estimates of car and light truck sales by region.[6]

[6] Additional detail on the processes used to disaggregate historical estimates of vehicle sales and forecasts of future vehicle sales from census regions to our five analysis regions is contained in Appendix A.

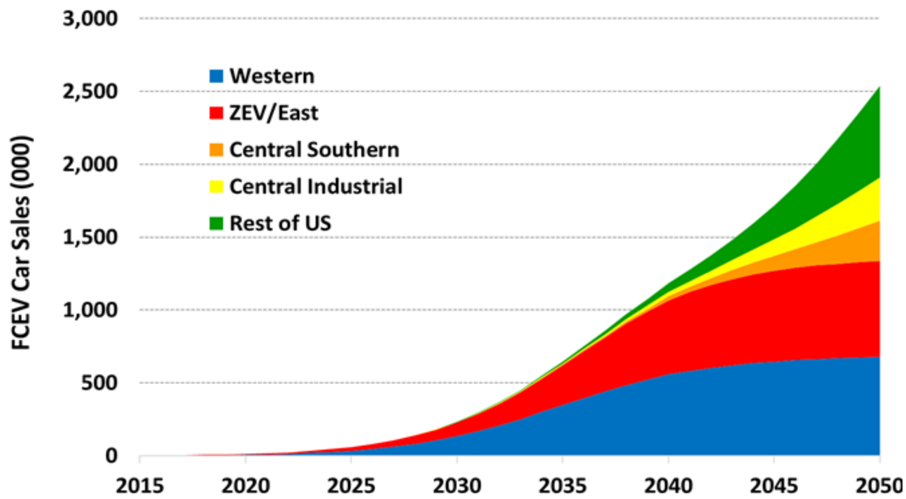

FIGURE 6 Sales of FCEV Cars by Region, 2015—2050

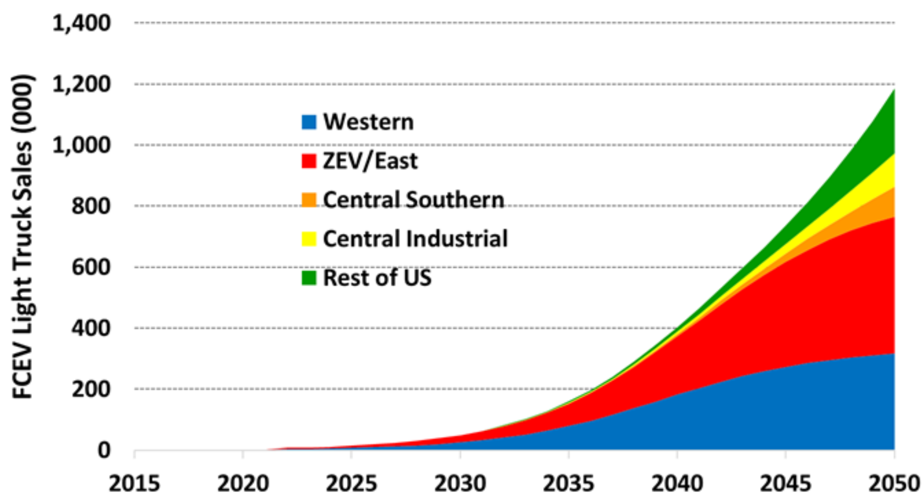

FIGURE 7 Sales of FCEV Light Trucks by Region, 2015–2050

2.2.3 Stock of FCEVs by Region

Figures 8 and 9 show VISION estimates of FCEV stocks by region, assuming that observed scrappage rates for conventional cars and light trucks also apply to FCEV cars and light trucks. Figure 10 shows the overall percent of U.S. LDV sales and stock represented by FCEVs nationwide. Note that the national FCEV penetration curves shown in Figure 10 are outputs (i.e., calculated from the sum of regional sales and stocks) in our scenario development process.

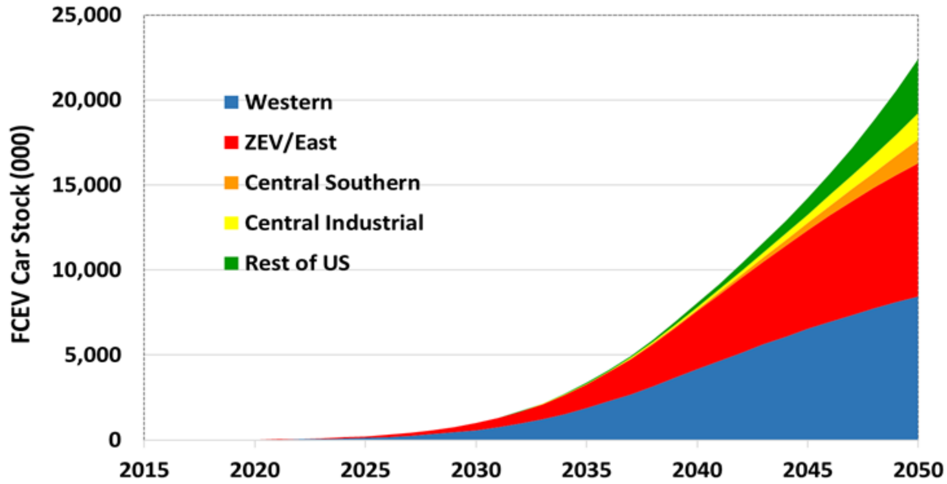

FIGURE 8 Stock of FCEV Cars by Region, 2015–2050

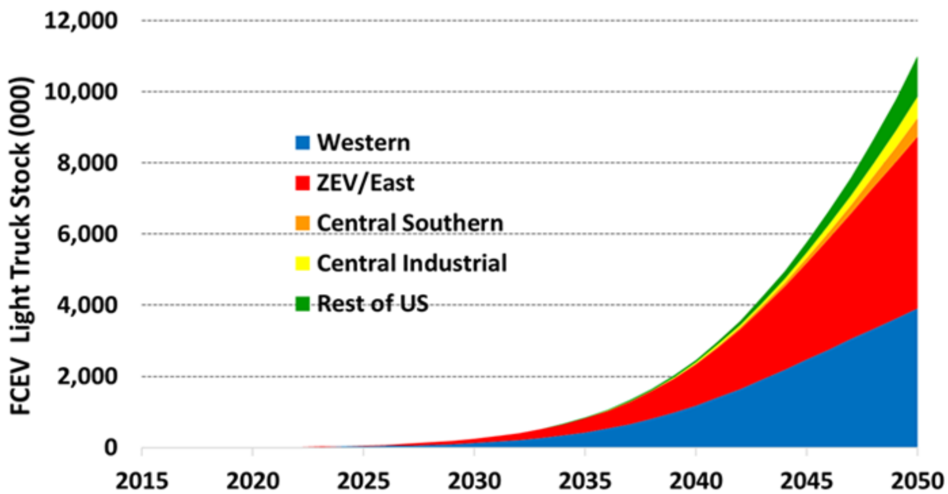

FIGURE 9 Stock of FCEV Light Trucks by Region, 2015–2050

As shown in Figure 10, FCEV sales represent approximately 20% of U.S. new LDV sales and 10% of the entire LDV feet in 2050 in the Core Multi-Market Scenario. Because of greater ongoing support in the Western and ZEV/Eastern regions, FC cars and light trucks represent a much larger share (35%) of 2050 sales in those regions. Similarly, FCEVs account for 32% and 28% of LDV stocks, respectively, in Western and ZEV/Eastern regions in 2050.

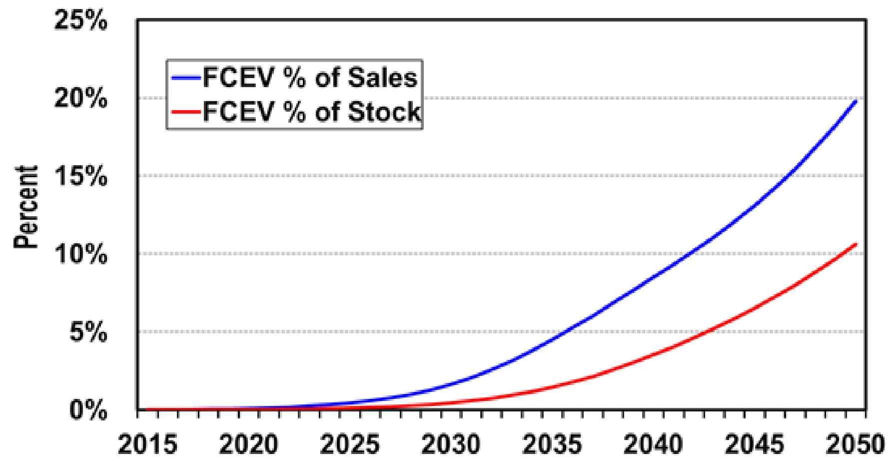

FIGURE 10 FCEVs as a Percentage of U.S. LDV Sales and Stock, 2015─2050

2.2.4 FCEV Manufacturing Cost

Argonne's Autonomie model was developed to estimate key features of current- and advanced-technology vehicle components (including manufacturing cost) under various assumptions including manufacturing scale, rate of technology progress and future fuel/energy price (Autonomie 2017). In order to leverage this and other FCTO-sponsored work, Autonomie output developed for FCTO's GPRA analysis (and documented in Islam et al. 2017) were used in our analysis. Those results correspond to a relatively high rate of technology progress for all advanced technologies which results in a relatively low retail price vis a vis conventional technology vehicles. They also assume achievement of FCTO's cost and performance targets for fuel cell stacks and systems (Wilson et al.2016; James et al. 2017a). Note that retail price is assumed to be 150% of the manufacturing cost of the vehicle (Islam et al. 2017).

In addition to the vehicle component costs obtained from the Autonomie GPRA runs, details on fuel cell stack and system costs were obtained from Strategic Analysis' FC manufacturing cost assessment (James 2017, James et al. 2017b) and FCTO's Program Record (Wilson et al. 2016). For this analysis the stack was assumed to represent 53% of FC system cost (James 2017, James et al. 2017b). Fuel cell stack and system component costs were assigned to the appropriate industries based in part on earlier analyses using the JOBS FC model.[7] For more information on FCEV, fuel cell system, and fuel cell stack costs, see Appendix B. For more information on the development of custom industries to represent FCEV and related component manufacturing, see Appendix C.

As in FCTO's GPRA analysis, our analysis used component costs for new mid-sized sedans and mid-sized sport utility vehicles (SUVs) to represent average costs for FC cars and light trucks, respectively. Figure 11 illustrates the breakdown of those costs over time as represented by new mid-sized sedans available for sale in the year indicated. In the GPRA

[7] For more information on the JOBS FC model, see http://jobsfc.es.anl.gov/.

Program Success Case, significant cost reduction occurs through the 2020's (Islam et al. 2017). As shown in the figure, fuel cell system, storage tank and battery costs decline through 2030 as these systems achieve program targets. Beyond 2030, glider costs rise somewhat as relatively more expensive lightweight materials replace conventional materials.

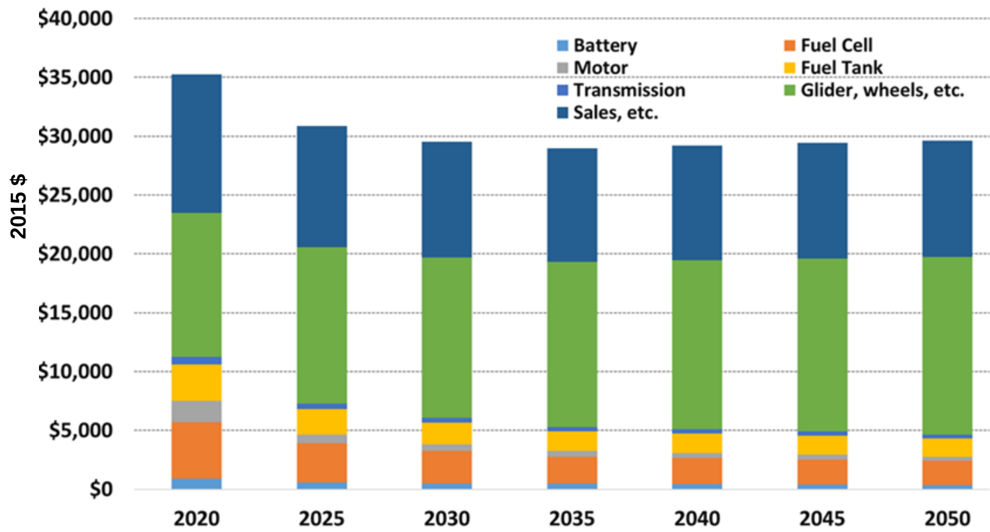

FIGURE 11 Average Manufacturing and Sales/Distribution Cost of FCEV Cars

2.2.5 FCEV Supply-Chain Dynamics

FCEV purchases affect numerous industries. Though primarily adding to motor vehicles and motor vehicle parts manufacturing industries, a number of intermediate industries that supply materials and other inputs to FCEV manufacturing experience an increase in demand which in turn requires them to increase employment and output. In order to capture these effects, data from Autonomie forecasts of production costs for conventional and FCEV cars and light trucks were used to estimate changes in annual purchases associated with LDV sales in our Core Multi Market Scenario. Initially, these changes are disaggregated by industry and region in order to reflect the supply-chain dynamics of each major component. Within the model these initial adjustments to purchasing patterns become increasingly broader and more difuse as market pentration increases over the scenario time frame. Ultimately, many different industries in different regions respond to support the manufacturing of FCEVs. Because of important differences in regional economies, however, manufacturing (and associated supply chain effects) vary by region. For additional discussion of industries see Section 3 and Appendix C.

2.2.6 FCEV Manufacturing Location

Today 38% of conventional cars and 80% of conventional light trucks sold in the U.S. are assembled at U.S. plants (BEA undated); the respective shares are much larger for electric-drive vehicles. According to industry sources 67.5% of PHEVs and 75.3% of BEVs sold in the U.S. in 2016 were assembled in the U.S. (Automotive News 2016). For this analysis we assume U.S. assembly of conventional LDVs for U.S. markets will continue at current rates (38% of cars; 80% of light trucks), and U.S. assembly of FCEVs for domestic markets will follow the BEV pattern for cars (75%) and the conventional pattern for light trucks (80%).[8] This is illustrated below in Figures 12 and 13. FCEV manufacturing is assumed to begin in the U.S. in 2020 which is five years after the initial penetration of FCEVs into the U.S. market. Until 2020, it is assumed that FCEVs are supplied by international manufacturers.

Today, U.S. manufacturing is concentrated in the Central Industrial region where approximately 74% of cars and 66% of light trucks made in the U.S. are assembled (Automotive News 2016). This is followed by the Rest of U.S. (see Figure 2) which accounts for 26% of the cars and 27% of the light trucks assembled in the U.S. The Central Southern region manufactures the remainder (7% of light trucks). Because of sparse supply chains, Western and ZEV/Eastern regions do not assemble conventional vehicles today and are unlikely to do so in the future.[9] FC stacks and systems are assumed to be manufactured in close proximity to vehicle assembly.

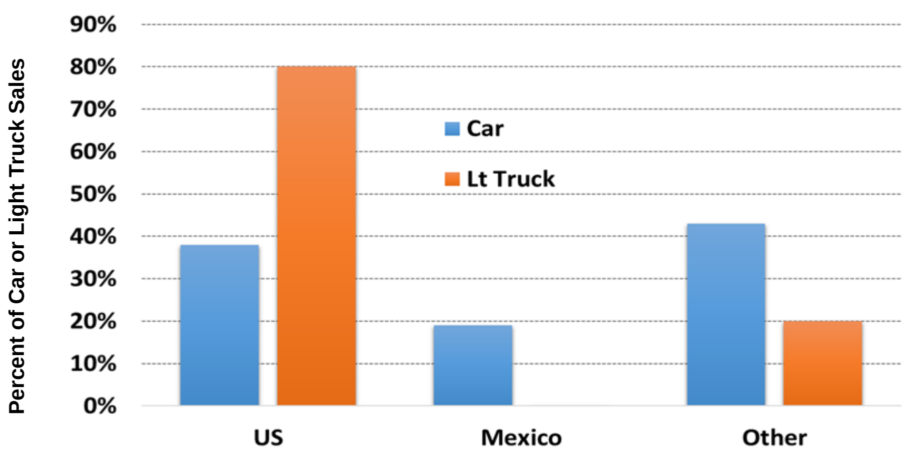

FIGURE 12 U.S. LDV Sales by Country of Origin

8 In 2016 no BEV light trucks were sold in the U.S. (Argonne 2017).

9 Tesla assembles BEVs in California at a former Toyota-GM plant. No other vehicle assembly occurs in the Western region.

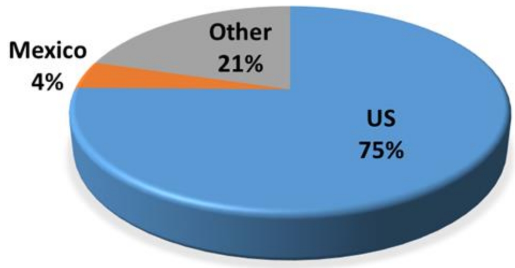

FIGURE 13 U.S. BEV Sales by Country of Origin

2.3 BASE SCENARIO

Our Base Scenario is essentially a “No Program” case in which FCEVs remain relatively costly and achieve limited market success. This is very similar to EIA’s AEO-2016 Reference Case. The Base Scenario is discussed only tangentially in this report since the focus here is on gross economic effects. A forthcoming technical memo will focus on net effects. The Base Scenario is discussed in that memo since it is key to calculating those impacts.

2.4 ALTERNATIVE CASES

Alternative cases of the Multi-Market Scenario are framed in the context of the share of FCEV production that occurs within the U.S. Although impacts also occur from FCEV imports, domestic assembly of FC stacks and systems is a key assumption of this study with major ramifications on results. Economic modeling is well suited to addressing this issue, since vehicle and component assembly can be modeled as activities affecting economic output and employment. Specifically, current LDV production is modeled as a web of first, second and third tier suppliers whose transactions are represented by purchase vectors within REMI. Adjusting those vectors to represent greater or lesser reliance on U.S. suppliers simulates the kinds of production changes being investigated and the economic impacts (including employment gains or losses) likely to occur across industries and regions. See Section 6 and Appendix C for a discussion of the adjustments made to model alternative levels of domestic versus foreign production in this analysis.

3 MODELING THE U.S. ECONOMY

Interactions between many industries are required to manufacture, distribute and sell FCEVs. These interactions between industries are spread throughout the economy as purchases and sales which in turn affect still other industries. Economic modeling provides a method for using the interactions between industries to evaluate the effects of proposed or envisioned changes to a region, in this case the economy of the United States and the five regions selected for this analysis.

Several standard economic models of varying complexity are available for evaluating changes to the economy based on new or changing activities. Most models rely on a variety of public data sources supplemented with proprietary information and analyses from a wide variety of sources.[10] By combining information from several sources, economic models provide a way to understand the structure of different industries and the interactions between industries within an economy.

To determine the effect of a change to the economy, one must estimate a base case (or "business as usual" case) and a change case (a scenario with assumptions about changes to particular activities within the economy). The economic impacts of the change are determined by measuring differences between the base case and the change case. The results will always be estimates which are highly dependent upon the assumptions contained in the two cases being compared. The base case and change scenario for this study are discussed below and in Section 2 of this report.

3.1 THE REMI MODEL

The model chosen for this project is REMI PI+ v1.7, which contains 160 industry sectors and which has been configured for the five custom regions shown in Figure 2.[11] REMI PI+ utilizes several integrated approaches including: input-output modeling (transactions between industries), general equilibrium (supply-demand balance), econometric analysis (advanced statistical and economic techniques), and economic geography (industry clustering and labor markets). This integrated approach allows for very detailed analyses and forecasting of changes to the economy and interactions between industries and regions over time.

Using detailed scenario inputs, the REMI PI+v1.7 model was run for each year from 2015 to 2050 for the Multi-Market Scenario described in Section 2 of this report. The employment impacts identified from those runs are the differences in employment in various industries between the with- and without-FCEV cases. Additional information about REMI PI+v1.7and the five custom regions is provided in Appendix C.

[10] For information on data sources used by the model chosen for this study, REMI PI+, see Appendix C.
[11] A perpetual license for REMI PI+ v.1.7 for this project was obtained from REMI, Inc. www.REMI.com.

3.2 ECONOMIC CONCEPTS AND TYPES OF IMPACTS

The economic impacts calculated by REMI PI+v1.7 and summarized in this report are estimates of gross supply-chain employment associated with the modeled activities (i.e., MDS or manufacturing, distribution and sale) of FCEVs. The analysis and results obtained from REMI PI+v1.7 rely on several key concepts:

- Jobs. A job is defined as one year of work (full-time or part-time) for one person.
- Gross Jobs. As discussed in this report, these are jobs associated with expenditures and activities for the MDS of FCEVs only. They include both full-time and part-time jobs. Jobs displaced by FCEVs and net jobs are not included in this report.[12]
- Supply-Chain Impacts. The economic impacts presented in this report are called industry supply-chain impacts. These are impacts directly associated with expenditures on FCEV manufacturing, distribution and sales. They include manufacturing and procurement of the necessary parts and input supplies for producing FCEVs including fuel cells, transportation of the vehicles and sales to customers. In this analysis, industry supply-chain impacts are equivalent to what are often referred to as direct and indirect economic impacts.
- Occupations. Information on occupations or types of work is presented in this report. Industries employ people working in many different occupations, and occupations are present across many industries. It can be helpful to look within an industry to understand the occupational breakdown of an activity. When modeling multiple activities, it is useful to look at occupations which may be present in multiple industries and observe impacts on those occupations.

3.3 U.S. ECONOMY IN THE ABSENCE OF FCEVS (BASE SCENARIO)

The REMI PI+v1.7 model provides a base case forecast for the U.S. economy over the study period 2015─2050. Since the data sources underlying REMI PI+v1.7 do not explicitly incorporate FCEV market penetration, the base case forecast depicts changes in the U.S. economy that are expected to occur in coming decades *in the absence of FCEVs*. The base case relies on industry standard sources and is widely used for economic and policy impact analysis by more than 50 federal and state agencies, as well as by many private firms and universities. In addition, REMI PI+v1.7 allows for the modification of the base case, a feature not found in other commercially available models.

For this project, the base case in REMI PI+ v1.7 was modified with information obtained from the AEO 2016 Reference Case to adjust components of selected macroeconomic indicators.[13] Because the AEO only provides a forecast through 2040, the year-over-year growth

[12] Gross jobs - displaced jobs = net jobs
[13] Since AEO-2016 has virtually no FCEVs in its Reference Case that portion of the REMI base case did not require modification.

rate for total GDP in the latter years of the AEO forecast was used for the 2041 to 2050-time period. A detailed description of the base case modification process is provided in Appendix C.

3.4 REMI MODIFICATIONS TO REPRESENT THE MULTI-MARKET SCENARIO

No existing model or economic data exist for simulating the widespread MDS of FCEVs. Unlike other macroeconomic models, however, REMI PI+ allows for the creation of new industries in the economy. This feature and the ability to model the dynamic interactions of multiple custom regions across the 2015−2050 timeframe of the study made the REMI model the most appropriate choice for this project.

Businesses that will provide MDS for FCEVs are likely to be related to industries currently in existence in the U.S. These "base" industries can be identified from NAICS (North American Industry Classification System) descriptions of industry activities and the types of goods being manufactured within those industries. Custom FCEV-specific industries can be defined by combining detailed cost data obtained from industry representatives, published studies, and Argonne's Autonomie model (as described in Section 2 and Appendix B) with modifications to the purchase patterns of the base industries.

REMI assists in this effort by providing intermediate inputs within an industry which can confirm if the supply chain represents the item of interest (e.g., a FC stack). Custom industries are needed if intermediate inputs or the labor portion of output for an existing industry differ from known values for that item of interest. Customization involves adjusting the mix of intermediate inputs or the labor portion of output to better reflect the modeled activity. Table 1 lists the custom industries developed to represent FCEV manufacturing and the associated base industries from which those industries were built. A more detailed description of the custom industry methodology is presented in Appendix C. It should be noted that no custom industries were developed to model the distribution and sale of FCEVs because the activities and purchase patterns of the involved industries are not expected to differ from those of conventional vehicles.

TABLE 1 Base Industries and Custom Industries Created in REMI PI+v1.7 to Model FCEV Manufacturing

Custom Industry	REMI PI+ Base Industry
FCEV Auto	Automobile Manufacturing (NAICS 336111)
FCEV Light Truck	Light Truck and Utility Vehicle Manufacturing (NAICS 336112)
Fuel Cell System (BoP)	Other Miscellaneous Electrical Equipment and Component Manufacturing (NAICS 335999)
Fuel Cell Stack	Other Miscellaneous Electrical Equipment and Component Manufacturing (NAICS 335999)

4 EFFECT OF FCEV MANUFACTURING, DISTRIBUTION AND SALE (MDS) ON EMPLOYMENT

The FCEV manufacturing, distribution, and sales portion of the Multi-Market Scenario is associated with 318,000 gross supply-chain jobs in 2050 as shown in Figure 14 below. Nearly 200,000 of these jobs are associated with FCEV distribution and sales while 120,000 are associated with manufacturing (Table 2). In the earliest years, only employment associated with distribution and sales occurs as no FCEV manufacturing is assumed to take place in the U.S. (see Section 2.2.6). U.S. manufacturing of FCEVs begins in 2020 and by 2050, over 120,000 gross supply-chain jobs are associated with FCEV manufacturing (vehicle plus fuel cell). Table 2 provides a breakdown of the employment impacts associated with manufacturing the vehicle, fuel cell system, and fuel cell stack. Sections 4.1 and 4.2 summarize employment impacts by industry and occupation, respectively.

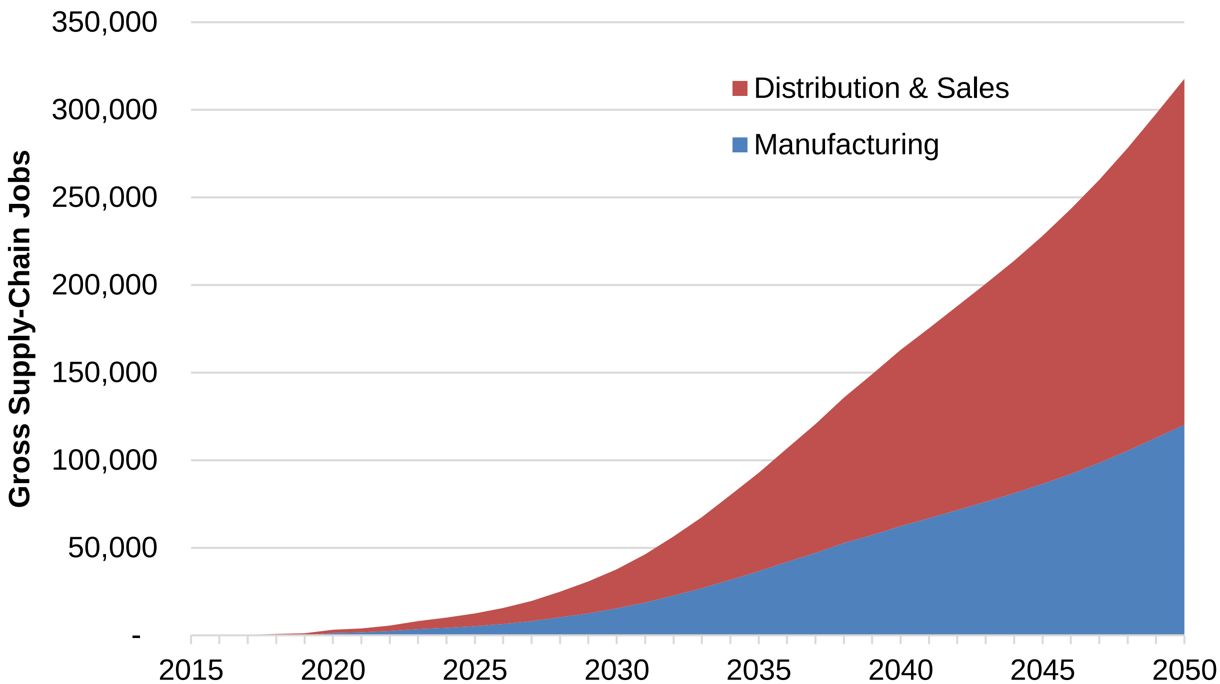

FIGURE 14 Gross Supply-Chain Jobs from MDS of FCEVs, Multi-Market Scenario

Table 2 below shows the number of gross supply-chain jobs for each activity in 2020, 2030, 2040, and 2050. Jobs associated with FCEV manufacturing represent approximately 40% of total jobs in the scenario, with the remaining approximately 60% are associated with FCEV distribution and sales.

TABLE 2 Total Gross Supply-Chain Jobs Associated with Manufacturing, Distribution and Sales of FCEVs

Gross Supply-Chain Jobs	2020	2030	2040	2050
FCEV Manufacturing	1,400	15,300	62,200	120,200
Vehicle without FC	1,100	12,900	53,800	104,500
Fuel Cell	300	2,400	8,400	15,700
FC System without stack	100	1,200	4,100	7,700
FC Stack	200	1,200	4,300	8,000
FCEV Distribution & Sales	1,800	22,400	100,700	197,500
TOTAL	3,200	37,700	162,900	317,700

4.1 MAJOR INDUSTRIES IN MANUFACTURE, DISTRIBUTION AND SALE OF FCEVs

Gross supply-chain jobs in the MDS of FCEVs are spread across many industries and sectors in the economy. As shown in Figure 15 below, the major industries are wholesale and retail trade which account for 40% of the total supply-chain jobs for MDS associated with FCEVs. These jobs include sales of the vehicles, as well as sales of intermediate services and materials. Professional, scientific, management and supportive services combined make up 21% of all jobs associated with FCEV MDS. Manufacturing across all portions of the supply chain stand at 11% of total FCEV MDS across the nation. All other sectors make up less than 10%. Regional effects are explored in Section 5 of this report.

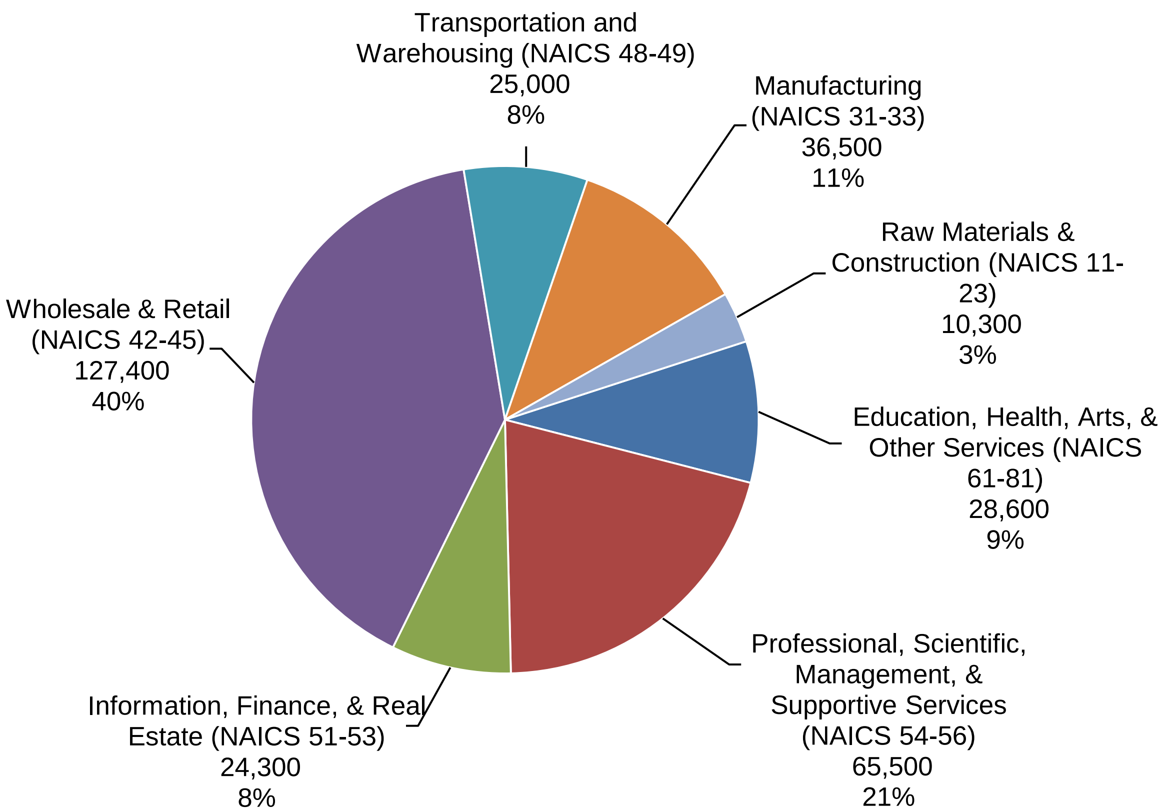

FIGURE 15 Gross Supply-Chain Jobs in FCEV Manufacturing by Industry, 2050

4.2 MAJOR OCCUPATIONS IN MDS OF FCEVs

Another way to understand employment impacts is to examine the occupations most affected by a change in the economy. REMI PI+v1.7 contains 95 occupations which cross industries. For example, occupations in fields categorized as STEM (Science, Technology, Engineering and Mathematics) exist in multiple industries, but the type of work and skills necessary are generally similar. Figure 16 below presents seven major occupational areas affected by MDS of FCEVs. Regional results are presented in Section 5 of this report. Additional information regarding the methodology for occupational results is presented in Appendix D.

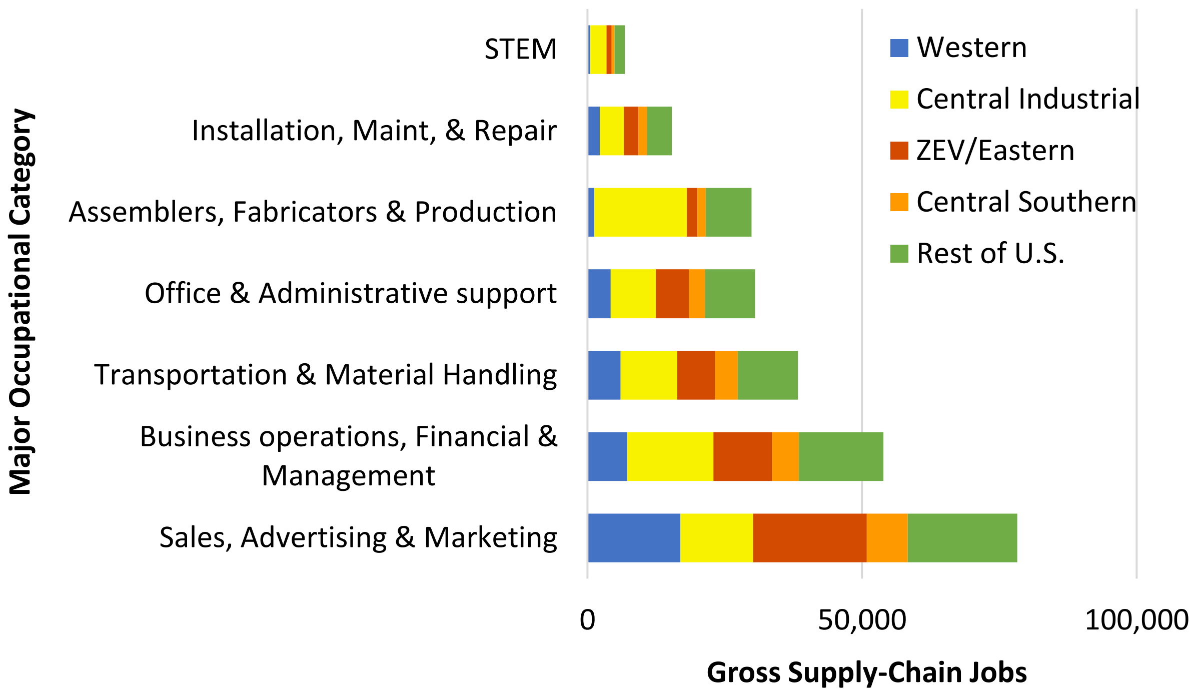

FIGURE 16 Jobs in MDS by Occupation, 2050

Table 3 provides additional detail on the individual occupations that were grouped into each major occupational category presented above. The major occupational category with the most jobs across all industries is sales, advertising and marketing with over 78,000 gross supply-chain jobs. In total, the occupations listed in Table 3 represent over 80% of the total gross supply-chain jobs associated with FCEV MDS estimated in the Multi-Market Scenario. The remainder (i.e., those not presented in Table 3) consist of a variety of occupations not related to the core activities in the MDS of FCEVs (e.g., food service workers). A more detailed discussion of the occupation data and estimation of jobs by occupation is provided in Appendix D.

TABLE 3 Occupations by Major Category

Occupational Category	Occupations
Sales, Advertising & Marketing	• Retail sales workers • Supervisors of sales workers • Sales representatives, wholesale and manufacturing • Sales representatives, services • Other sales and related workers • Advertising, marketing, promotions, public relations, and sales managers • Art and design workers • Media and communication workers
Business operations, Financial & Management	• Business operations specialists • Financial clerks • Financial specialists • Top executives • Operations specialties managers • Other management occupations • Material recording, scheduling, dispatching, and distributing workers • Lawyers, judges, and related workers • Legal support workers
Transportation & Material Handling	• Material moving workers • Motor vehicle operators • Supervisors of transportation and material moving workers • Other transportation workers
Office & Administrative support	• Information and record clerks • Supervisors of office and administrative support workers • Secretaries and administrative assistants • Other office and administrative support workers
Assemblers, Fabricators & Production	• Assemblers and fabricators • Metal workers and plastic workers • Other production occupations • Supervisors of production workers
Installation, Maintenance, & Repair	• Other installation, maintenance, and repair occupations • Vehicle and mobile equipment mechanics, installers, and repairers • Electrical and electronic equipment mechanics, installers, and repairers • Supervisors of installation, maintenance, and repair workers
STEM (Science, Technology, Engineering and Mathematics)	• Engineers • Drafters, engineering technicians, and mapping technicians • Physical scientists • Life, physical, and social science technicians • Mathematical science occupations • Life scientists • Social scientists and related workers

5 REGIONAL VARIATIONS IN ECONOMIC IMPACTS

Economic impacts vary across the regions due to market penetration assumptions, location of industries involved in vehicle manufacturing, and other regional characteristics including labor pool and labor productivity. Employment impacts at the regional level are described in detail in the sections below.

5.1 CHARACTERISTICS OF SELECTED REGIONS

In order to study the regional effects of the Multi-Market Scenario, REMI PI+v1.7 was configured into five regions of the U.S. Each such region can be modeled individually as a stand-alone region or combined with other regions to produce total impacts for the U.S. as a whole. The five regions were selected based on several factors including current policies that influence market penetration, and industry concentrations such as motor vehicle manufacturing. These regions include:

- Western
- Central Industrial
- ZEV/Eastern
- Central Southern
- Rest of U.S.

The Western region, including California, has been a leader in energy conservation and the use of alternative energy sources. In the Multi-Market Scenario, sales of FCEVs begin earlier and rise most rapidly in this region.

The Central Industrial region has the greatest concentration of auto and auto parts manufacturing in the country. In the Multi-Market Scenario, it is assumed that this region continues to have a dominant role in auto and auto parts manufacturing, including hydrogen fuel cells for transportation.

The ZEV/Eastern region includes a collection of states in the northeast part of the U.S. This region has made significant strides to adopt plans for transportation sources with reduced carbon emissions. In the Multi-Market Scenario, this region is the second region to deploy a significant number of FCEVs.

The Central Southern region has significant petrochemical industries and is dominant in upstream energy exploration and development industries.

The Rest of U.S. region is a combination of all other states in the U.S. The prior four regions were selected based on state level policies and industry concentrations that were specific to the scenario. The remaining states were combined to represent the demand and supply-chain response for the rest of the country.

Table 4 summarizes regional characteristics of importance to FCEV manufacturing and sales scenarios. Data presented are for 2014. Column 1 shows the current portion of LDV sales by region as modeled in VISION (see Section 2). Rest of U.S. is the largest region in our analysis and therefore captures the largest portion of demand for vehicles, 31%, in 2014. This is followed by the ZEV/Eastern region which accounted for 25% of LDV sales in 2014. Total employment, presented in column 2, exhibits a pattern similar to vehicle sales. Finally, column 3, which shows the regional distribution of employment in motor vehicle manufacturing, indicates the extent to which the industrial composition of each region differs from that of the nation as a whole. As an example, in 2014, the Central Industrial region had 18% of new vehicle sales and 18% of total national employment across all industries. However, the Central Industrial region accounted for 68% of all employment in vehicle manufacturing, an indicator of the strong concentration of vehicle manufacturing in the region relative to both new vehicle demand and share of national employment.

TABLE 4 Regional Characteristics as a Percent of National, 2014

	Parameter and Source		
	LDV Sales	Total Employment	Employment in Vehicle Manufacturing (NAICS 3361)[14]
Region	VISION	REMI PI+ 1.7	REMI PI+ v1.7
Western	14%	16%	3%
Central Industrial	18%	18%	68%
ZEV/Eastern	25%	21%	2%
Central Southern	11%	12%	6%
Rest of U.S.	31%	33%	21%

Economic impacts stem from the market penetration assumptions that were presented in Section 2. In addition to those demand-side assumptions, several supply-side assumptions were made about when various industries involved respond to FCEV market signals. Two key assumptions about industry response are presented in Table 5 below. These assumptions include: (1) the timing of when industries involved in distribution and sales will respond to market penetration, and (2) when industries involved in manufacturing FCEVs will respond to market penetration. It is assumed that demand for FCEVs will generate an immediate response by sectors that participate in distribution and sales (e.g., transportation, wholesale, and retail). Industries involved in manufacturing are assumed to delay their response for five years after

[14] Data presented is from REMI PI+ v1.7 and is presented to illustrate regional variation in vehicle manufacturing employment. The values here were not used to develop scenario assumptions about FCEV vehicle manufacturing locations presented in Chapter 2.

initial market introduction. Table 5 below summarizes these assumptions. As discussed in Section 2.2.6, the location of FCEV assembly is assumed to be similar to that of conventional vehicles assembly.

TABLE 5 Summary of Market Response Assumptions about MDS of FCEVs

Region	First Year of FCEV Sales	First Year of FCEV Manufacturing
Western	• 2015 Autos • 2019 Light trucks	No vehicle manufacturing
Central Industrial	• 2028 Autos • 2032 Light trucks	2020 Autos & light trucks
ZEV/Eastern	• 2018 Autos • 2022 Light trucks	No vehicle manufacturing
Central Southern	• 2028 Autos • 2032 Light trucks	2020 Light trucks
Rest of U.S.	• 2028 Autos • 2032 Light trucks	2020 Autos & light trucks

5.2 WESTERN REGION EMPLOYMENT IMPACTS

The Western region is the first region to experience market pentation of FCEVs. It is assumed that the Western region imports all FCEVs from the Central Industrial, Central Southern, or Rest of U.S. regions, or from other countries. Therefore, the directly impacted industries within the Western region are related primarily to the distribution and sale of FCEVs. Indirectly, however, industries in the Western region support vehicle manufacturing in other regions by supplying components or other goods and services. Table 6 below summarizes gross employment impacts associated with the MDS of FCEVs in the Western region.

TABLE 6 Gross Supply-Chain Jobs in MDS of FCEVs, Western Region

Gross Supply-Chain Jobs	2020	2030	2040	2050
FCEV Manufacturing	50	400	1,300	2,300
FCEV Distribution & Sales	900	9,900	37,900	44,300
Total Supply-Chain MDS Jobs	**950**	**10,300**	**39,200**	**46,600**

Overall, the Western region experiences a positive impact in gross supply-chain jobs related to FCEVs, primarily from distribution and sales. Employment impacts from FCEV manufacturing are noticeably small due to the lack of direct FCEV manufacturing activity occurring in the Western region. These impacts are due entirely to supply-chain support of FCEV manufacturing.

Gross supply-chain employment impacts from FCEV distribution and sales reach over 44,000 jobs by 2050. These jobs include both direct employment from transportation and retail sectors and supply-chain support of those industries. Overall, it is estimated that the Western region will experiences a gross supply-chain employment impact of almost 47,000 jobs due to FCEV MDS.

5.2.1 Employment Impacts by Industry, Western Region

Figure 17 below presents the breakdown of employment impacts by industry for the Western region. As presented in Table 6 above, the employment impacts in the Western region are primarily due to the distribution and sales of FCEVs. This is highlighted in Figure 17 below where 62% of employment is occurring in the wholesale and retail sectors. Employment in professional, scientific, management, and support services comprises 16% of employment impacts which is the next largest group. The remainder of the sectors represent less than 10% each.

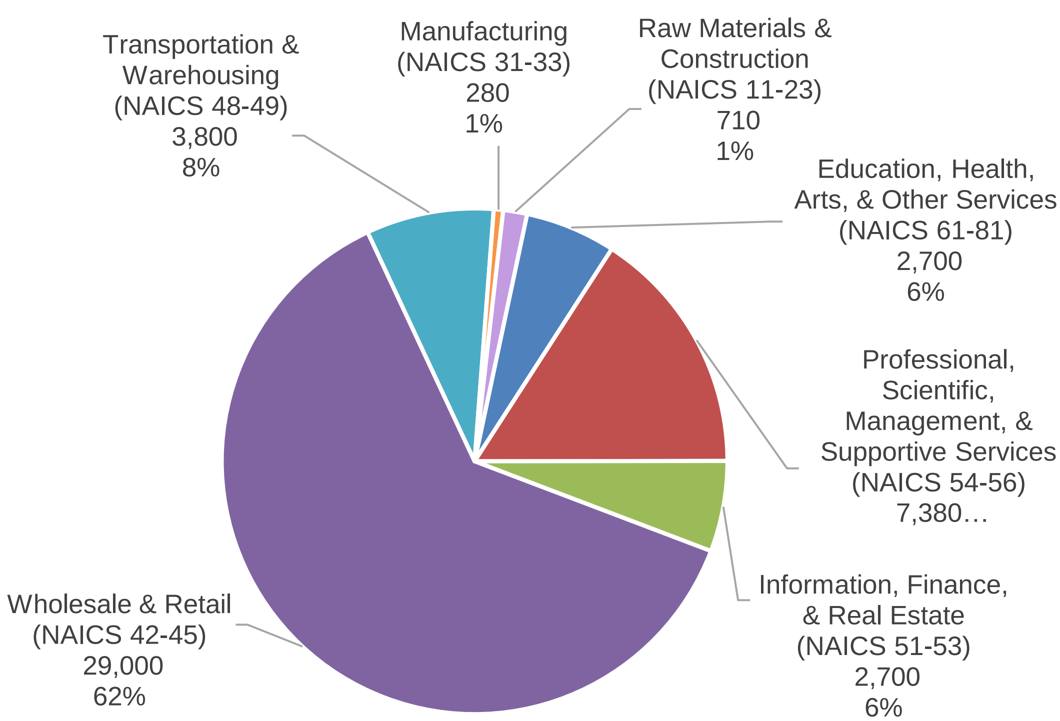

FIGURE 17 MDS Gross Supply-Chain Jobs, Western Region, 2050

5.2.2 Employment Impacts by Occupation, Western Region

Employment impacts are also examined at the occupation level. Figure 18 below presents the occupations in order of employment impact for the Western region only. The top occupations impacted are within sales, advertising and marketing with almost 17,000 gross supply-chain jobs. This is followed by occupations in business operations, financial and management with over 7,000 jobs. Transportation and warehousing comprise 6,000 jobs.

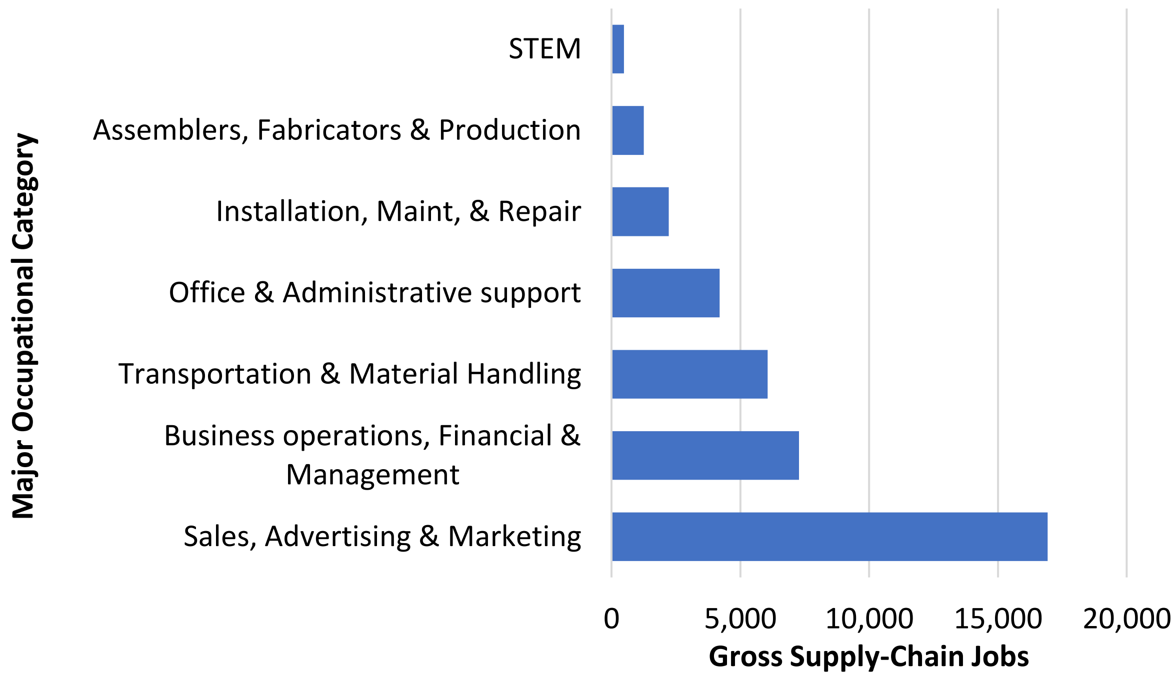

FIGURE 18 MDS Jobs by Major Occupational Category, Western Region, 2050

5.3 CENTRAL INDUSTRIAL REGION EMPLOYMENT IMPACTS

The Central Industrial region is the primary FCEV manufacturing region within this analysis. It is assumed that manufacturing will begin in 2020 with only the Western and ZEV/Eastern regions demanding FCEVs (Table 5 above). Market penetration of FCEVs in the Central Industrial region begins in 2028. This is captured in Table 7 below where gross supply-chain employment grows by more than a factor of 10 between 2020 and 2030 due to the significant increase in FCEV demand. The majority of gross supply-chain employment impacts occurring in the Central Industrial region are the result of manufacturing activities. This is shown in Table 7 below where over 60,000 or 70% of gross supply chain jobs are estimated to be due to manufacturing of FCEVs in 2050.

TABLE 7 Gross Supply-Chain Jobs in MDS of FCEVs, Central Industrial Region

Gross Supply-Chain Jobs	2020	2030	2040	2050
FCEV Manufacturing	700	7,600	31,600	61,300
FCEV Distribution & Sales	100	1,300	7,000	27,000
Total Supply-Chain MDS Jobs	**800**	**8,900**	**38,600**	**88,300**

5.3.1 Employment Impacts by Industry, Central Industrial Region

Figure 19 below presents the breakdown of employment impacts by industry for the Central Industrial region. As presented in Table 7 above, the employment impacts in the Central Industrial region are primarily due to the manufacturing of FCEVs. This is highlighted in Figure 19 below where 26% of employment occurs in manufacturing followed closely by professional, scientific, management, and supportive services with 25%. Wholesale and retail represent 23% of total employment impacts in 2050. Finally, the remainder of the sectors represent less than 10% each of total employment.

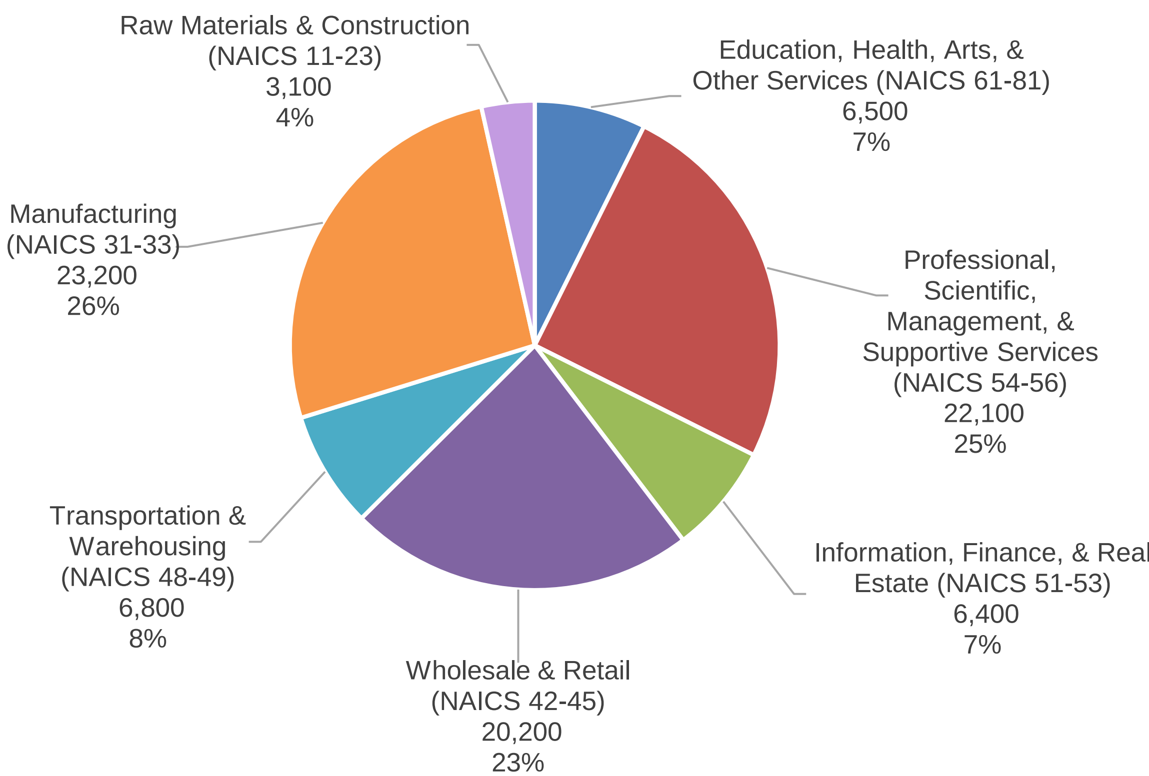

FIGURE 19 MDS Gross Supply-Chain Jobs, Central Industrial Region, 2050

5.3.2 Employment Impacts by Occupation, Central Industrial Region

Employment impacts are also examined at the occupation level. Figure 20 below presents the occupations in order of employment impact for the Central Industrial region only. The top occupations are categorized as assemblers, fabricators and production with almost 17,000 jobs. This is followed by occupations in business operations, financial and management with almost 16,000 jobs. Sales, advertising and marketing occupations make up over 13,000 jobs. Transportation and materials handling occupations represent over 10,000 jobs, and office and administrative support occupations make up over 8,000 jobs.

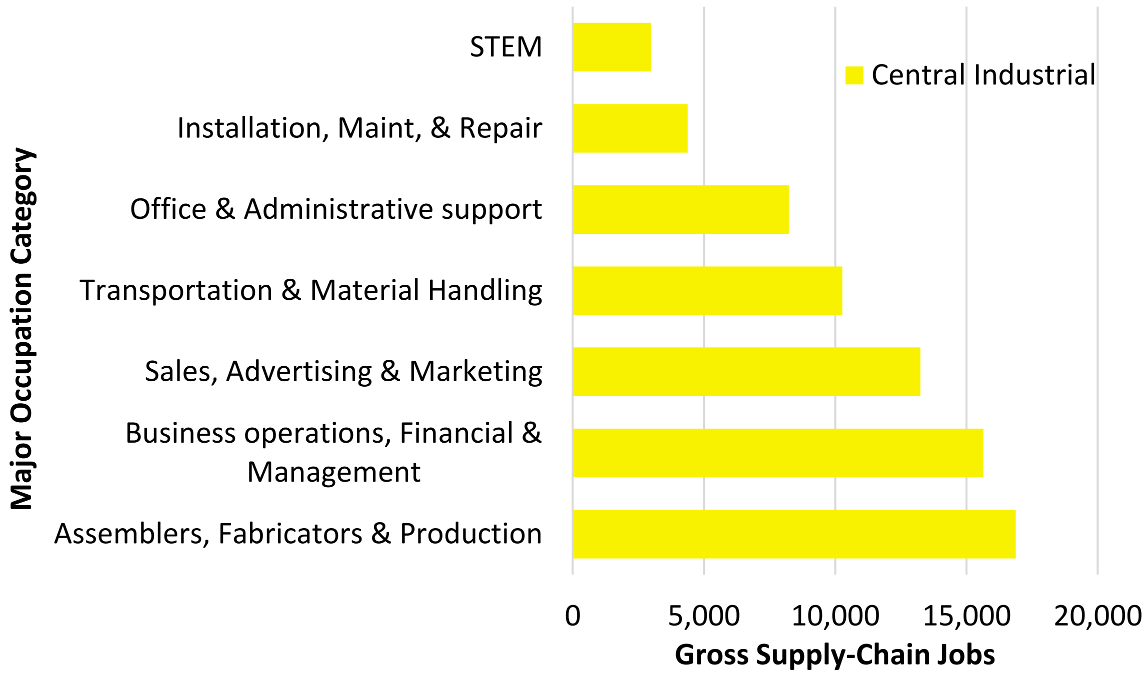

FIGURE 20 MDS Jobs by Major Occupational Category, Central Industrial Region, 2050

5.4 ZEV/EASTERN REGION EMPLOYMENT IMPACTS

The ZEV/Eastern region is the second region to experience market pentation of FCEVs. Similar to the Western region, it is assumed that the ZEV/Eastern region imports all FCEVs from either the Central Industrial, Central Southern, or Rest of U.S. regions, or from other countries. Therefore, the directly impacted industries within the ZEV/Eastern region are related primarily to distribution and sales of FCEVs. Through supply-chain impacts, the ZEV/Eastern region supports vehicle manufacturing indirectly. Overall, 81% or over 50,000 gross supply-chain job impacts in 2050 are due to FCEV distribution and sales. Table 8 below summarizes the gross employment impacts of the Multi-Sector Scenario in the ZEV/Eastern region.

TABLE 8 Gross Supply-Chain Jobs in MDS of FCEVs, ZEV/Eastern Region

Gross Supply-Chain Jobs	2020	2030	2040	2050
FCEV Manufacturing	100	1,500	6,100	11,800
FCEV Distribution & Sales	500	7,300	35,300	50,500
Total Supply-Chain MDS Jobs	**600**	**8,800**	**41,400**	**62,300**

5.4.1 Employment Impacts by Industry, ZEV/Eastern Region

Figure 21 below presents the breakdown of gross supply-chain employment impacts by industry for the ZEV/Eastern region. As presented in Table 8 above, the employment impacts in the ZEV/Eastern region are primarily due to the distribution and sales of FCEVs. This is highlighted in Figure 18 below where 55% of employment is occurring in the wholesale and retail sectors. Employment in professional, scientific, management, and support services comprise 18% of employment impacts which is the next largest group. The remaining sectors represent less than 10% each.

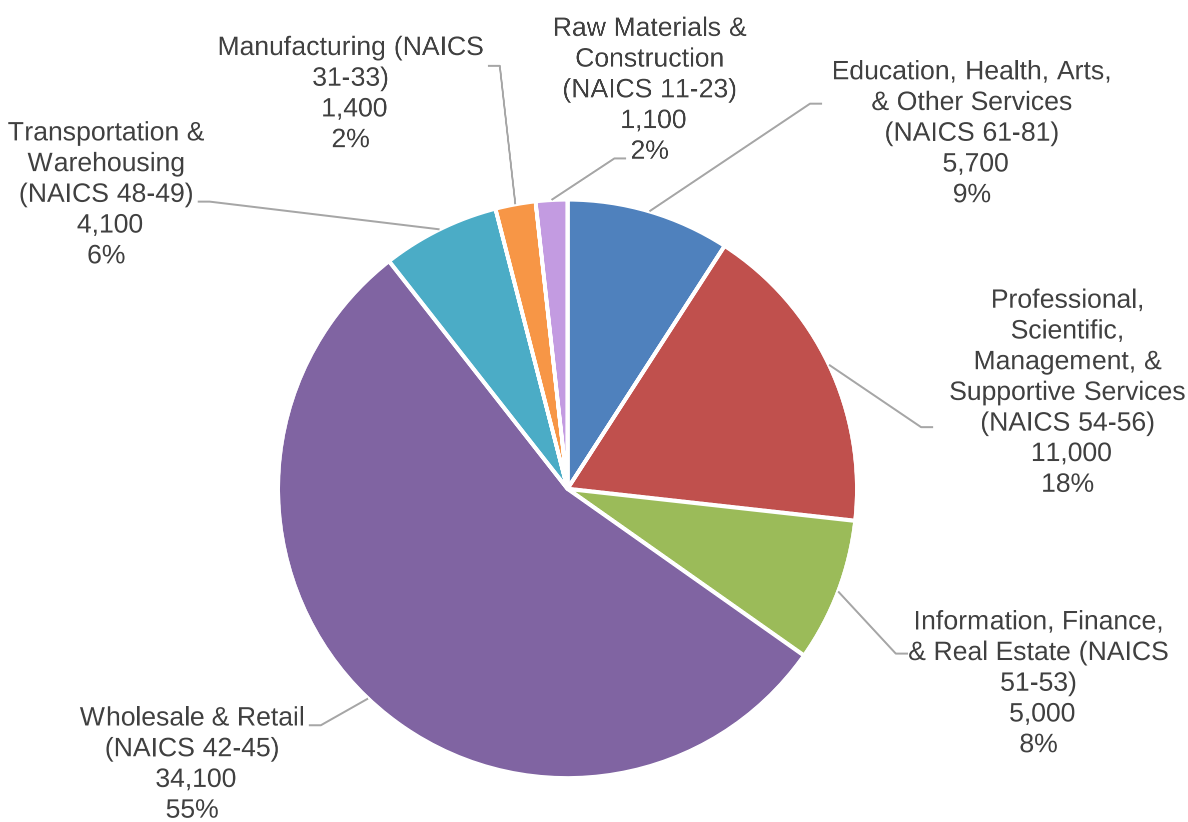

FIGURE 21 MDS Gross Supply-Chain Jobs, ZEV/Eastern Region, 2050

5.4.2 Employment Impacts by Occupation, ZEV/Eastern Region

Employment impacts are also examined at the occupation level. Figure 22 below presents the occupations in order of gross supply-chain employment impact for the ZEV/Eastern region only. The top occupations impacted are in sales, advertising and marketing with over 20,000 jobs. This is followed by occupations within business operations, financial and management at almost 11,000 jobs. Transportation and materials handling occupations represent almost 7,000 jobs, and office and administrative support occupations make up over 6,000 jobs.

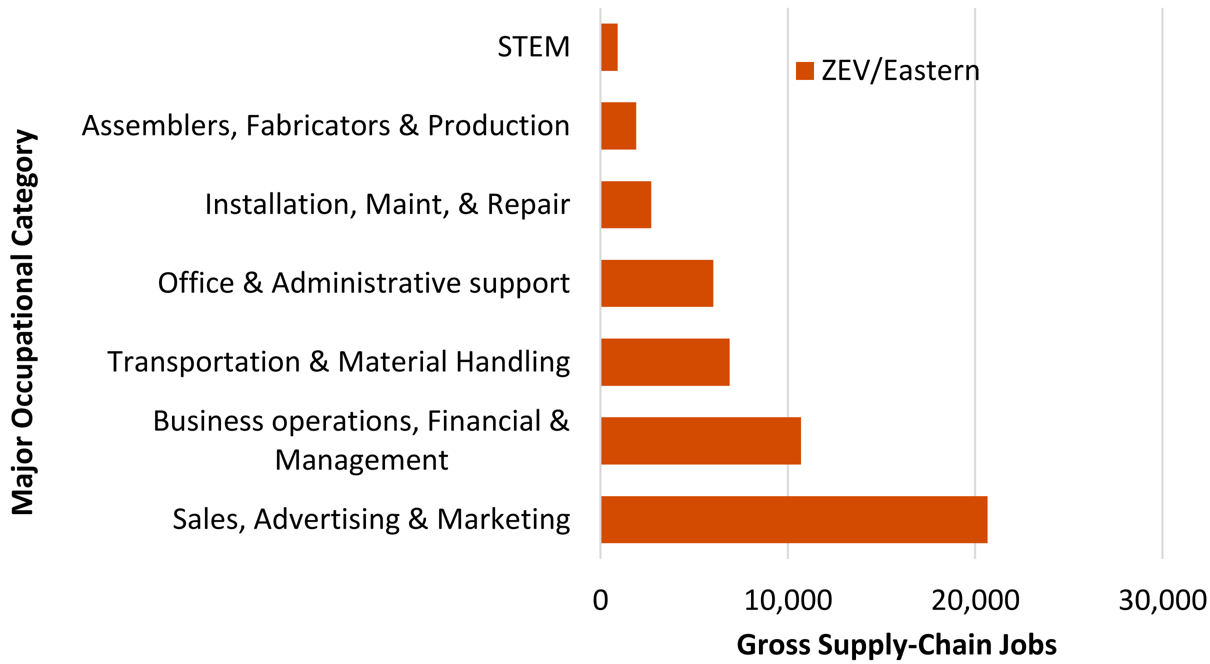

FIGURE 22 MDS Jobs by Major Occupational Category, ZEV/Eastern Region, 2050

5.5 CENTRAL SOUTHERN REGION EMPLOYMENT IMPACTS

Gross supply-chain employment impacts from FCEV MDS in the Central Southern region are summarized below in Table 9. The Central Southern region is one of the regions that manufactures FCEVs, although on a smaller scale than Central Industrial and Rest of U.S. regions. Employment impacts through 2040 are evenly split between manufacturing FCEVs and supporting their distribution and sales through supply-chain effects. As FCEVs begin to penetrate the Central Southern market in 2028 and new sales gain momentum, distribution and sales impacts become the dominant impact in the region by 2050. This is highlighted in Table 9 below as employment grows by more than an order of magnitude from 2020 to 2030 and continues to grow from there. Overall, gross supply-chain employment impacts from FCEV MDS in the Central Southern region are estimated to be almost 30,000 jobs in 2050.

TABLE 9 Gross Supply-Chain Jobs in MDS of FCEVs, Central Southern Region

Gross Supply-Chain Jobs	2020	2030	2040	2050
FCEV Manufacturing	100	1,000	4,000	7,600
FCEV Distribution & Sales	90	1,000	5,500	22,300
Total Supply-Chain MDS Jobs	**190**	**2,000**	**9,500**	**29,900**

5.5.1 Employment Impacts by Industry, Central Southern Region

Figure 23 below presents the breakdown of gross supply-chain employment impacts by industry for the Central Southern region. As presented in Table 9 above, the employment impacts in the Central Southern region are primarily due to the distribution and sales of FCEVs. This is highlighted in Figure 23 below where 41% of employment is occurring in the wholesale and retail sectors. Professional, scientific, management, and support services sectors comprise 19% of employment impacts which is the next largest group. The remaining sectors represent 10% or less each of the gross supply-chain job impacts in the region in 2050.

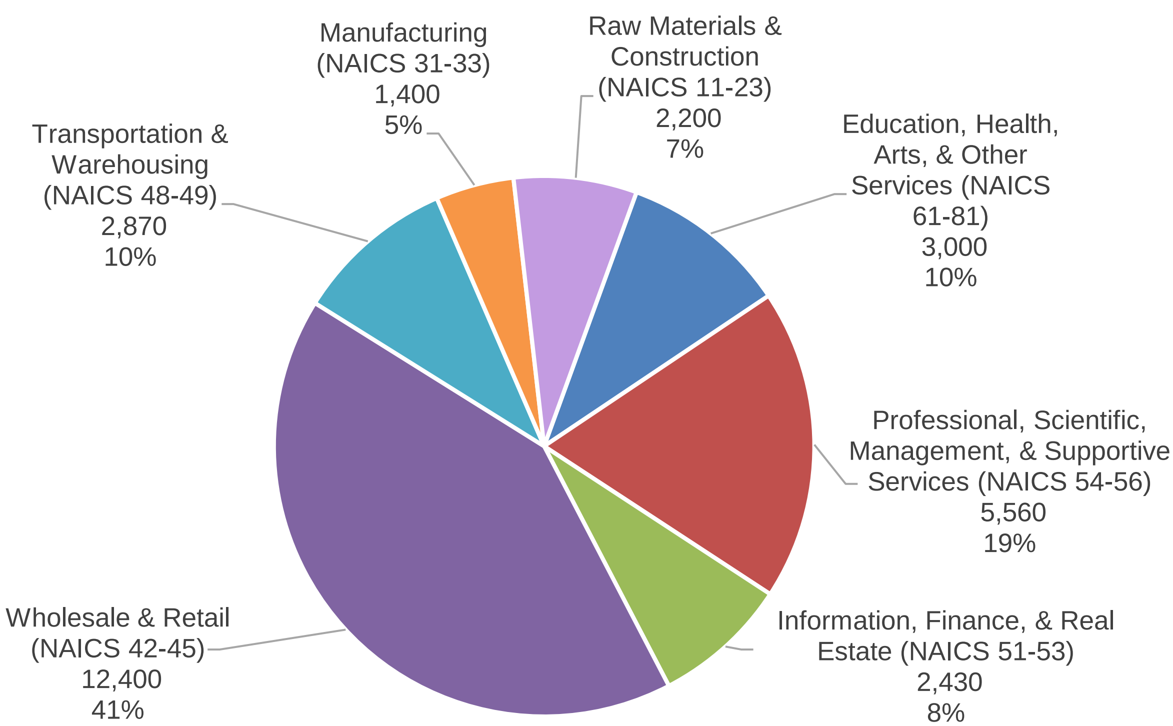

FIGURE 23 MDS Gross Supply-Chain Jobs, Central Southern Region, 2050

5.5.2 Employment Impacts by Occupation, Central Southern Region

Employment impacts are also examined at the occupation level. Figure 24 below presents the occupations in order of gross supply-chain employment impact for the Central Southern region only. The top occupations impacted are within sales, advertising and marketing with over 7,000 jobs. This is followed by occupations within business operations, financial and management at almost 5,000 jobs. Transportation and materials handling occupations represent over 4,000 jobs, and office and administrative support occupations make up almost 3,000 jobs.

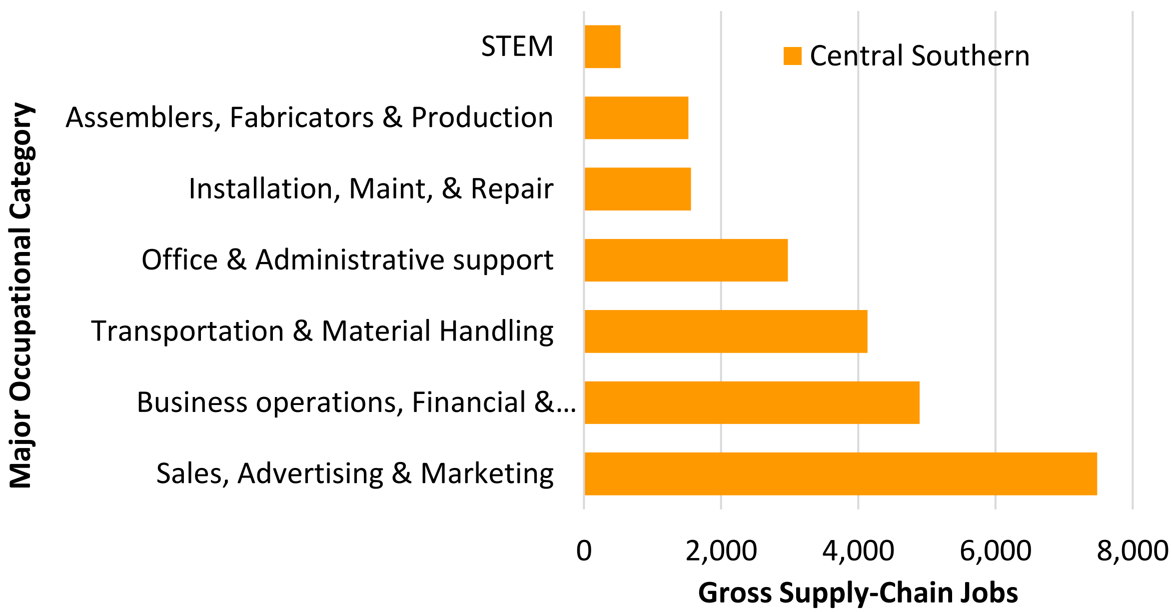

FIGURE 24 MDS Jobs by Major Occupational Category, Central Southern Region, 2050

5.6 EMPLOYMENT IMPACTS IN THE REST OF THE U.S. REGION

The Rest of U.S. region is the second major manufacturing region within this analysis. It is assumed that manufacturing will begin in 2020 and at that time only the Western and ZEV/Eastern regions will demand FCEVs (Table 5 above). Market penetration begins in 2028 for the remaining regions. This is captured in Table 10 below where gross supply-chain employment grows by roughly a factor of 12 between 2020 and 2030 due to the significant increase in FCEV demand. Employment impacts occurring in the Rest of U.S. region are more balanced between FCEV manufacturing activities and FCEV distribution and sales activities. This is shown in Table 10 below where 41% of jobs estimated in 2050 are due to manufacturing of FCEVs and 59% are due to distribution and sales.

TABLE 10 Gross Supply-Chain Jobs in MDS of FCEVs, Rest of U.S. Region

Gross Supply-Chain Jobs	2020	2030	2040	2050
FCEV Manufacturing	400	4,700	19,300	37,200
FCEV Distribution & Sales	240	2,900	15,000	53,400
Total Supply-Chain MDS Jobs	**640**	**7,600**	**34,300**	**90,600**

5.6.1 Employment Impacts by Industry, Rest of U.S. Region

Figure 25 below presents the breakdown of employment impacts by industry for the Rest of U.S. region in 2050. At the sector level, wholesale and retail sectors still capture a large portion of employment impacts at 35%. Professional, scientific, management, and supportive services capture the next largest portion of employment impacts with 21%. Most of the remaining industries range from 8% to 12% of gross supply-chain jobs.

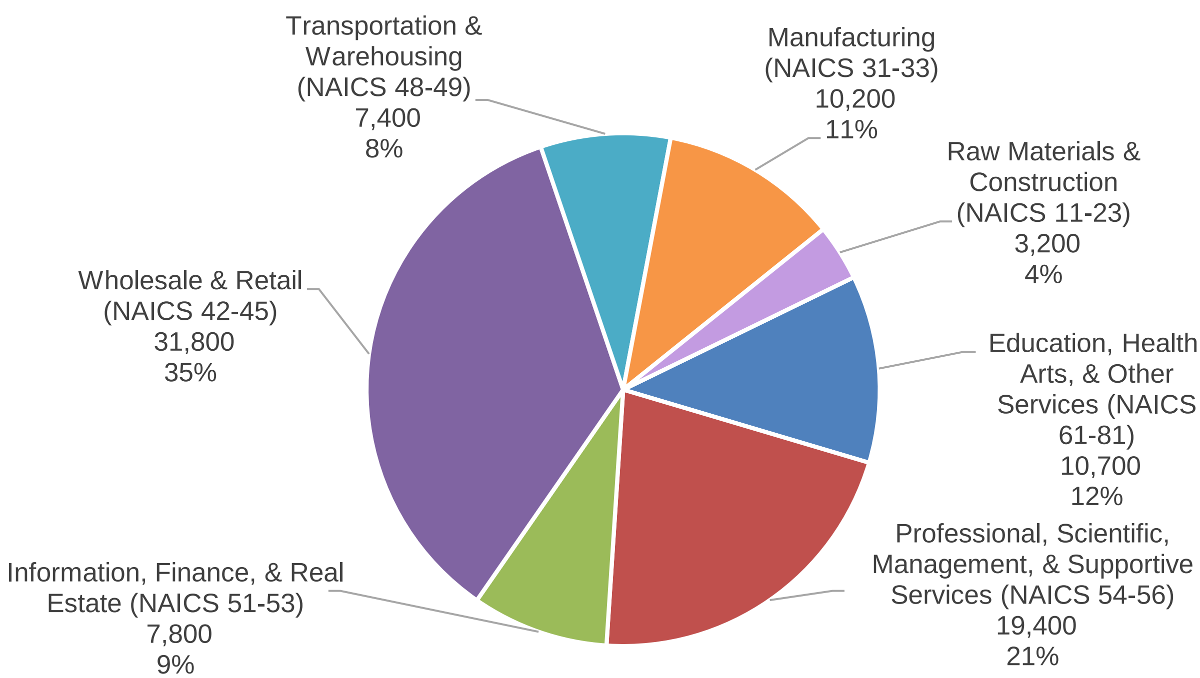

FIGURE 25 MDS Gross Supply-Chain Jobs, Rest of U.S., 2050

5.6.2 Employment Impacts by Occupation, Rest of U.S. Region

Employment impacts are also examined at the occupation level. Figure 26 below presents the occupations in order of gross employment impact for the Rest of U.S. region only. The top occupations impacted are in sales, advertising and marketing with almost 20,000 jobs. This is followed by occupations in business operations, financial and management at over 15,000 jobs. Transportation and materials handling occupations represent almost 11,000 jobs, and office and administrative support occupations make up over 8,000 jobs.

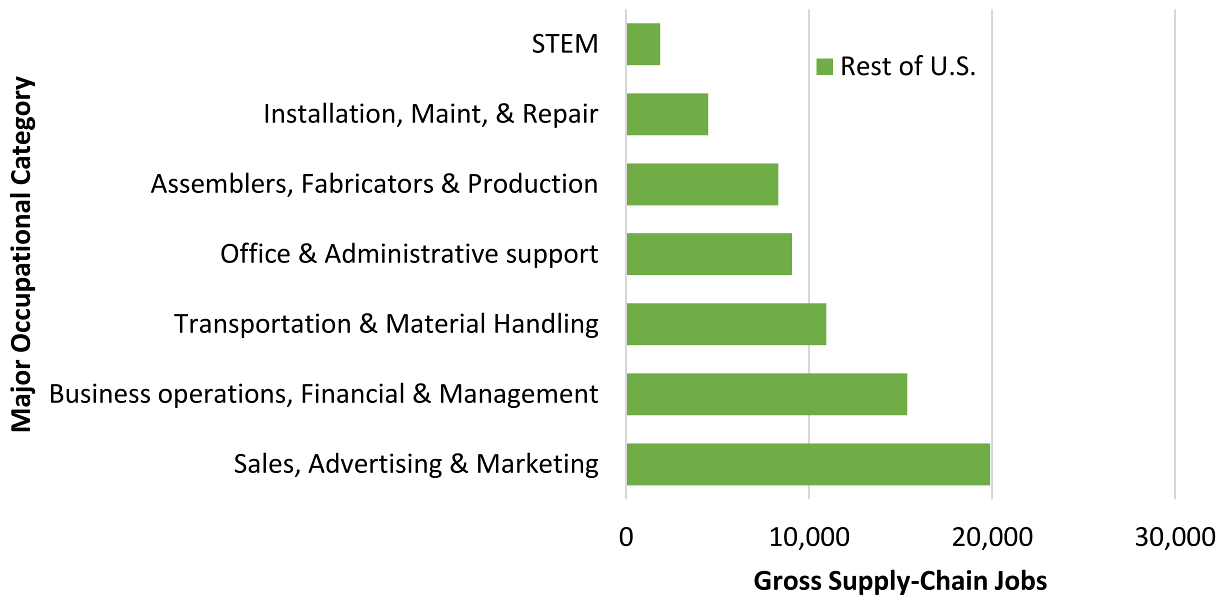

FIGURE 26 MSD Jobs by Major Occupational Category, Rest of U.S., 2050

6 ALTERNATIVE SCENARIOS AND EMPLOYMENT IMPACTS ASSOCIATED WITH U.S. MANUFACTURING

6.1 U.S MANUFACTURING COMPETITIVENESS

Global competition to develop and produce advanced technology products has been fierce and is likely to remain so. Germany, Japan, South Korea, China and several other countries are actively investing in hydrogen and fuel cell technologies and advanced manufacturing processes to enhance the competitive position of their domestic industries. U.S. companies are competing individually and through cooperative efforts like H_2USA to develop the products and manufacturing expertise to succeed on a global scale. But how important is domestic manufacturing to gaining the economic advantages associated with new technologies? Though this analysis is able to address only one portion of that question (i.e., the effect of stack, system and FCEV manufacturing on gross employment), the effort provides important insights into how FC market development can affect U.S. employment and how those effects might be distributed.

6.2 ALTERNATIVE SCENARIOS OF FCEV MANUFACTURING LOCATION

This report considers only the gross supply-chain impacts of FCEV production and sales. As described in Section 2, the assumed quantity of FCEVs produced in the U.S. is based only on (1) sales of FCEVs in the U.S. (i.e., exports are not considered), and (2) the percentage of those FCEVs which are assumed to be produced in the U.S.

In addition to the Multi-Market Scenario, two additional scenarios were defined to investigate the impact of domestic manufacturing. The “Current U.S. Assembly” Scenario assumes that beginning in 2020, the share of FCEVs manufactured in the U.S. to meet U.S. demand is equal to the current share (circa 2015) of conventional vehicles manufactured in the U.S. to meet U.S. demand for LDVs. For this scenario, 38% of cars and 80% of light trucks are manufactured in the U.S. The final scenario (“Exclusive U.S. Assembly”) assumes that beginning in 2020, 100% of FCEVs (cars and light trucks) are manufactured in the U.S. Table 11 summarizes these assumptions.

The regional shares of U.S. FCEV manufacturing remain the same across all three scenarios. FCEV cars are manufactured in the Central Industrial and Rest of U.S. regions while FCEV light trucks are manufactured in the Central Industrial, Rest of U.S., and Central Southern regions. See Section 2.2.6 for more information about regional manufacturing assumptions.

TABLE 11 FCEV Sales Shares by U.S. Assembly Scenario

	Percent of U.S. FCEV Sales from U.S. FCEV Manufacturers	
Scenario	Cars	Light Trucks
Multi-Market Scenario	75%	80%
Current U.S. Assembly	38%	80%
Exclusive U.S. Assembly	100%	100%

As with the Multi-Market Scenario, all fuel cell systems, as well as all fuel cells stacks, are assumed to be manufactured in the U.S. *for FCEVs that are manufactured in the U.S.* According to the data within REMI PI+v1.7, in recent years, between 65% and 75% of U.S. demand for the motor vehicle parts industry is met by U.S. suppliers.[15] The assumption that 100% of fuel cell systems and fuel cell stacks demanded by FCEV manufacturers are produced by U.S. suppliers yields notable economic impacts to the U.S.

The location of manufacturing for the non-fuel cell portions of the FCEV as well as the components of the fuel cell system and fuel cell stack are determined by the regional purchase coefficient (RPC) data within the REMI PI+v1.7 model. For more information on demand variables, please see Appendix C.

6.3 EMPLOYMENT IMPACTS OF ALTERNATIVE FCEV MANUFACTURING LOCATION SCENARIOS

The assumption about what fraction of FCEVs sold in the U.S. are produced in the U.S. has enormous implications on the estimated economic impacts, especially as the market share of FCEVs increases. Higher levels of FCEV production increase demand from U.S.-based suppliers through the supply chains for FCEVs as well as fuel cell systems.

Figure 27 below shows gross supply-chain employment for the three scenarios described above. Moving from the Current U.S. Assembly Scenario to the Multi-Market Scenario increases gross supply-chain employment by approximately 40,000 jobs in 2050. Moving still further, to the Exclusive U.S. Assembly Scenario, adds another 40,000 gross supply-chain jobs in 2050.

The Central Industrial and Rest of U.S. regions are especially impacted by changes in U.S. FCEV manufacturing as those regions are assumed to manufacture the vast majority of FCEVs, fuel cell systems, and fuel cells stacks. Figure 28 below shows the gross supply-chain employment impacts by region for the two alternative scenarios relative to the Multi-Market Scenario. Even regions in which no FCEVs are assumed to be manufactured experience changes

[15] REMI PI+ v.1.7, build 4139

in gross supply-chain employment impacts based upon the different U.S. manufacturing percentage scenarios.

The economic impacts associated with distribution and sales (presented in Section 3) are unaffected as those impacts are assumed to be identical regardless of where the FCEV is manufactured.

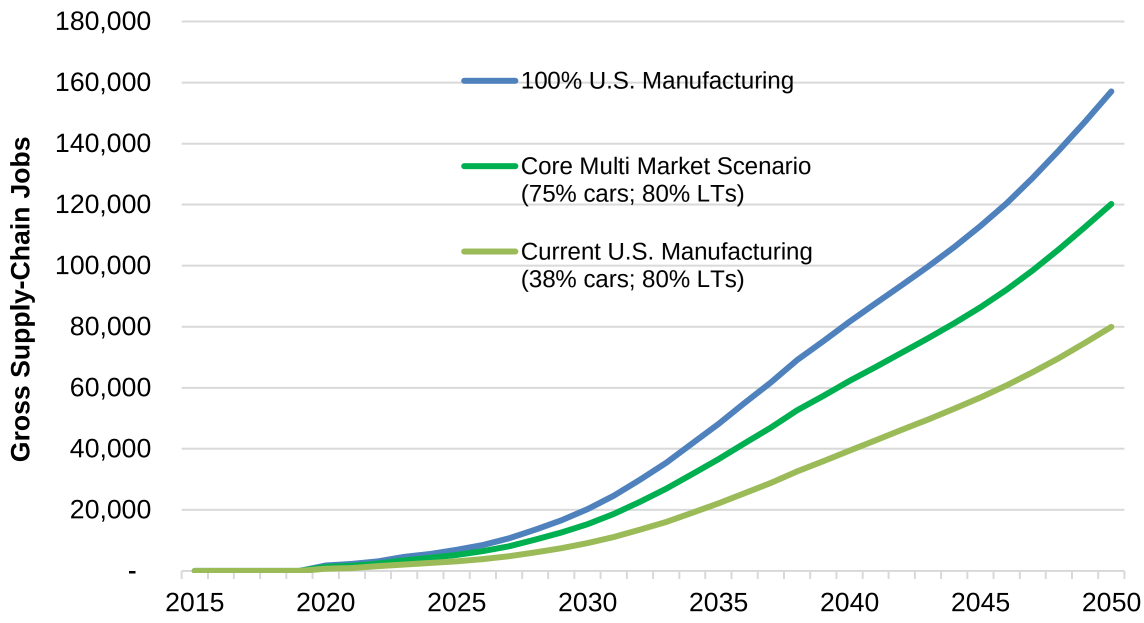

FIGURE 27 Employment Impact of Alternative U.S. Manufacturing Scenarios

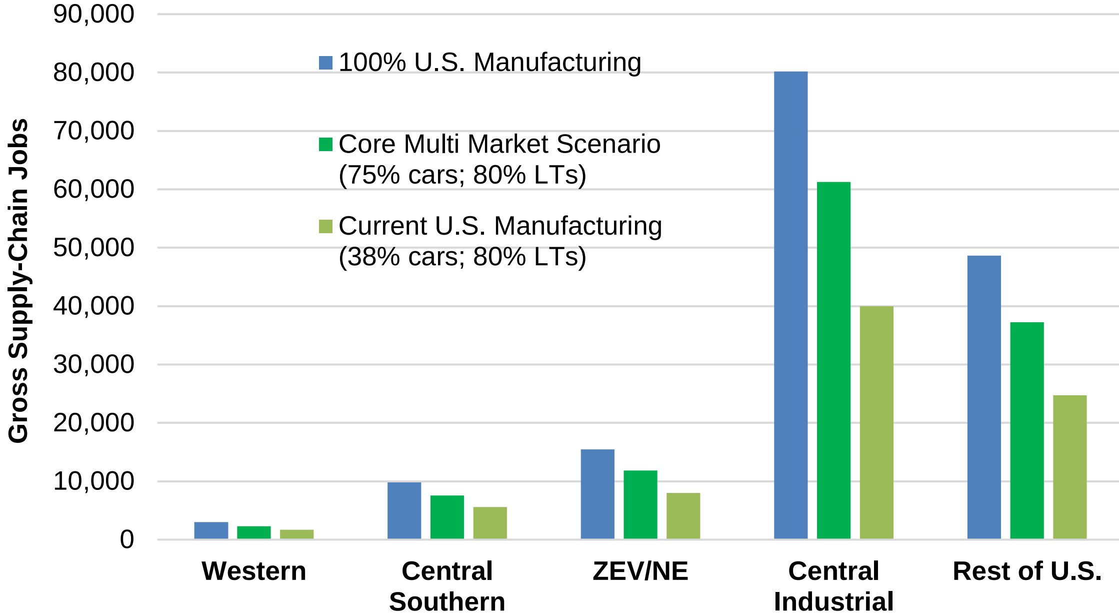

FIGURE 28 Impact of Alternative U.S. Manufacturing Scenarios by Region

7 CONCLUSIONS

This project is a multi-year effort to update DOE's 2008 Report to Congress, (*Effects of a Transition to a Hydrogen Economy on Employment in the United States*) in order to reflect current levels of technology advancement and anticipated fuel prices, economic activity and market success. This report documents a portion of that work, focusing on describing the context and details of a reference scenario of FCEV deployment in five U.S. regions and presenting estimates of gross employment under three manufacturing assumptions. Under this scenario (called the Core Multi-Market Scenario) approximately 120,000 gross supply-chain jobs associated with FCEV manufacturing, and 200,000 jobs associated with the distribution and sale of 3.7 million FCEV cars and light trucks are estimated nationally in 2050. A companion technical memorandum planned for early 2018, will describe aspects of the "core" scenario regarding hydrogen production, delivery and retail fueling infrastructure; provide estimates of gross employment associated with those economic activities; and present estimates of net employment effects associated with the manufacture, distribution and sale of FCEVs and the hydrogen needed to support those vehicles.

Briefly, our results suggest the following:

- While manufacturing of FCEVs is associated with significant job creation under the Multi-Market Scenario, distribution and sale of those FCEVs is associated with even more job creation. Some of these jobs may displace jobs in conventional vehicle manufacturing, distribution and sales; others may be entirely "new" jobs. The extent of displacement versus new job creation is currently being investigated.

- FCEV-related employment occurs in the region where the FCEV and its components are produced, in the region where the FCEV is sold, and in other regions whose industries provide goods and services throughout the various supply chains.

- In the earliest years of the Multi-Market Scenario, only the Western and ZEV/Eastern regions experience significant FCEV sales. By 2050, however, FCEVs are sold across the entire U.S., producing significant employment impacts in all regions due to distribution and sales. Nearly 200,000 jobs across the U.S. are associated with FCEV distribution and sales in 2050.

- Over 120,000 supply-chain jobs are associated with manufacturing FCEVs in the U.S under the Multi-Market Scenario. Employment related to manufacturing occurs primarily in the historic industrial heartland (i.e., Central Industrial region) and Rest of U.S. regions, but all regions see impacts associated with FCEV manufacturing due to demand for various parts in the supply chain.

- In 2050, significant gains in gross employment occur in all regions due to FCEV manufacturing, distribution and sale. Job gains range from 30,000 to 90,000 jobs per region.

The assumption about what fraction of FCEs sold in the U.S. are produced in the U.S. has a major effect on economic impacts, especially as the market share of FCEVs increases. Shifting from the Multi-Market Scenario assumption that roughly 70 % of FCEVs sold in the U.S. will be manufactured here to one in which 100% of FCEVs are manufactured in the U.S. yields nearly 40,000 additional jobs. The Central Industrial and Rest of U.S. regions are especially impacted by greater or lesser domestic manufacturing of FCEVs as those regions are assumed to manufacture the vast majority of FCEVs, FC systems, and FC stacks.

It must be emphasized that the analyses and estimates of gross supply-chain jobs presented in this report are part of a larger story. They apply only to the MSD associated with light-duty FCEVs and do not account for jobs displaced as FCEVs replace conventional vehicles. Nonetheless, they offer important insights into the types of employment impacts that may be anticipated, where they are most likely to occur, and how they might be managed to amplify their positive effects. As results associated with the MSD of the hydrogen needed to support those vehicles become available, these conclusions will be expanded in light of those insights and implications.

8 REFERENCES

Argonne National Lab, 2017. *E-Drive Monthly Sales Update*. Accessed Sept. 2017 at https://www.anl.gov/energy-systems/project/light-duty-electric-drive-vehicles-monthly-sales-updates.

Automotive News, 2016. North American Car and Truck Assembly Plants. Accessed Sept. 2017 at http://www.autonews.com/section/datacenter.

Autonomie, 2017. Accessed Sept. 2017 at http://www.autonomie.net/publications/fuel_economy_report.html.

Bush, G.W., *Hydrogen Fuel Initiative*, 2003. Jan. 28. Accessed Sept. 2017 at https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/benefits.pdf.

California Air Resources Board (CARB), 2016. *Annual Evaluation of Hydrogen Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*, July. Accessed Sept. 2017 at https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2016.pdf.

Islam, E., 2017. Personal communication, Sept.

James, B. 2017. Personal communication, March.

James, B., J. Huya-Kouadio and C. Houchins, 2017a. *Fuel Cell Systems Analysis*, DOE Hydrogen and Fuel Cells 2017 Annual Merit Review, Washington, DC, June 8. Accessed Sept. 2017 at https://www.hydrogen.energy.gov/pdfs/review17/fc163_james_2017_o.pdf.

James, B., J. Huya-Kouadio, C. Houchins and D. DeSantis, 2017b. *Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2016 Update.* Strategic Analysis. Accessed Sept. 2017 at https://energy.gov/sites/prod/files/2017/06/f34/fcto_sa_2016_pemfc_transportation_cost_analysis.pdf.

Mintz, M. and C. Mertes, 2017. *Employment Impacts of Hydrogen and Fuel Cell Technologies*, DOE Hydrogen and Fuel Cells 2017 Annual Merit Review, Washington, DC, June 6. Accessed Sept. 2017 at https://www.hydrogen.energy.gov/pdfs/review17/sa035_mintz_2017_o.pdf.

Stephens, T., A. Birkey and D. Gohlke, 2017a. Vehicle Technologies and Fuel Cell Technologies Office Research and Development Programs: Prospective Benefits Assessment Report for FY2018, ANL/ESD-17/22 Argonne National Laboratory, Argonne, IL, November.

Stephens, T., R. Levinson, A. Brooker, C. Liu, Z. Lin, A. Birkey and E. Kontou, 2017b. *Comparison of Vehicle Choice Models*, ANL/ESD-17/19, Argonne National Laboratory, Argonne, IL, October.

U.S. Department of Commerce, Bureau of Economic Analysis (BEA), undated. https://www.bea.gov/national/xls/gap_hist.xlsx)

U.S. Department of Energy (DOE), 2008. *Effects of a Transition to a Hydrogen Economy on Employment in the United States: Report to Congress*, July. Accessed Sept. 2017 at https://energy.gov/sites/prod/files/2014/03/f12/epact1820_employment_study.pdf.

U.S. Energy Information Administration (EIA), *Annual Energy Outlook 2016*, 2016. Accessed Sept. 2017 at https://www.eia.gov/outlooks/aeo/.

Wilson, A., J. Marcinkoski and D. Papageorgopoulos, 2016. *Fuel Cell System Cost – 2016*, DOE Hydrogen and Fuel Cells Program Record 16020, Sept. 30.

This page intentionally left blank.

APPENDIX A: NATIONAL AND REGIONAL SCENARIOS

This effort was informed by several recent and ongoing efforts supported by the FCTO and other offices within DOE. Specifically, benefits analyses conducted in response to the Government Performance and Results Act (GPRA) was a particularly important input, as were the Energy Information Administration's (EIA's) Annual Energy Outlook (AEO), ongoing work from the H@Scale and H_2USA initiatives, and analyses by the California Fuel Cell Partnership (CaFCP) and California Air Resources Board (CARB).

The GPRA effort provided many of the initial assumptions upon which the Multi-Market Scenario was built since it required translating program goals into model inputs. These included average fuel economy and incremental costs of new vehicles that incorporate DOE-supported technologies and delivered hydrogen price. The Program Success case, developed for the GPRA effort, is particularly relevant as it assumes that future technology improvements and cost reductions meet FCTO program goals. GPRA in turn relies on several other tools which provided key inputs to our analysis. These include the Autonomie (see Appendix B), VISION and GREET models.

The EIA's Annual Energy Outlook (AEO) is the official DOE-wide projection of future U.S. energy supplies, demands and prices. These projections provided key inputs to our Multi-Market Scenario for fossil fuel prices, LDV sales, vehicle travel and vehicle ownership (EIA 2016). However, since the AEO Reference Case assumes limited market success of FCTO-supported technologies, our market penetration forecasts derive from GPRA, not AEO. As discussed in Section 2.2.1, our market penetration assumptions are based on the average market share achieved in 2050 by all four of the models in the GPRA analysis. Using that share as a target for regions with significant ZEV policy support, market penetration curves were developed for each of the five regions considered in our analysis.

The regionalization process may be summarized as a series of intermediate steps with national estimates computed at the end:

- Regional FCEV Market Penetration: National shares of FCEV cars and light trucks consistent with FCTO program goals and price targets for delivered H_2 were estimated for 2050. These target shares were used in combination with standard technology substitution theory to estimate regional penetration curves.

- *Regional FCEV Sales*: Regional FCEV sales were computed from regional FCEV shares and AEO forecasts of LDV sales.

- *Regional FCEV Stock*: Regional FCEV stocks were estimated from annual FCEV sales less scrappage.

- Regional Hydrogen Use: Regional H_2 consumption was estimated from FCEV car and light truck stocks, utilization and fuel economy.

- Total FCEV Sales, Stock and H_2 Use: Regional estimates were summed to national totals.

A.1 REGIONAL FCEV MARKET PENETRATION

In response to GPRA, FCTO estimates the impact of its program through 2050 using metrics like energy use, emissions and ownership cost. Impacts are based on an analysis of market performance using DOE-supported vehicle choice models developed by researchers at several national labs (Stephens et al. 2017a). The models estimate shares of conventional ICE vehicles (ICEVs), FCEVs and PHEVs of various ranges and technologies (Stephens et al. 2017b).

As discussed in Section 2.2, there are major differences in initial estimates of FCEV market penetration from the several choice models for all vehicle types and sizes modeled. Rather than selecting a preferred set, we pooled the results and applied a general decision rule. We assumed FCEVs would capture half of the average market shares projected for all electric-drive choices (i.e., FCEV and PHEV choices among mid-sized autos and mid-sized SUVs) across all of the models in 2050 *in regions with significant ZEV policy support*. These shares then became target penetration rates for FCEV autos and light trucks in our Western and ZEV/Eastern regions in 2050 (see Figure A1).

FIGURE A1 Regions Represented in Separate Market Penetration Scenarios

The trajectory assumed for the regional market penetration curves relies on technology substitution theory (Mansfield 1961, Blackman 1974, Paul 1979). Initially, a new technology is assumed to substitute for an old technology at a very slow rate. After a few years the rate increases, then slows, and market share eventually reaches a saturation point. The market penetration pattern approximates an S-shaped curve. To model FCEV market penetration we employed a logit formulation previously used by Santini (1989):

$$t = \delta + \beta \ \ln[F\{t\}/(1 - F\{t\})] + \mu$$

In this model δ and β are coefficients that become scalar factors determining the shape of the market penetration curve, and μ is the error term. The scalar δ defines the midpoint of the symmetric curve in terms of time and β determines the rate at which the new technology penetrates the market.

In calculating market shares, the 2050 shares became curve-fitting targets for the Western region and regional roadmaps were used to project shares for 2015−2022. Market penetration in the ZEV/Eastern region was assumed to follow the same initial trajectory as in the Western region, but with a five-year delay. Market penetrations in the Central Industrial, Central Southern and Rest of U.S. regions were assumed to follow the same initial trajectory but with another 10-year delay.

A.2 REGIONAL FCEV SALES

As discussed in Section 2.2.2, the AEO Reference Case includes forecasts of LDV (car and light truck) sales by U.S. Census region. Using historical shares of auto and light truck sales by state within each of these regions, these forecasts were disaggregated by state. Then, estimates of state vehicle sales by technology (FCEV and non-FCEV) were developed using the above-discussed FCEV market penetration curves (assuming the regional curve applies to each state in that region) and the VISION model. Regional FCEV sales were computed as the sum of state sales.

A.3 REGIONAL FCEV STOCK

With regional FCEV sales as input, VISION was run for each region to generate FCEV stocks. Scrappage rates were assumed to be constant across region, time and technology.

A.4 REGIONAL HYDROGEN DEMAND

Regional H_2 demand was estimated from regional FCEV car and light truck stocks, annual utilization and fuel economy using the VISION model. Utilization was assumed to be constant across region, time and technology. Fuel economy was assumed to vary as shown in Table A1. Note that while EPA-test fuel economy estimates came from the Autonomie model, correction factors used to translate those values to on-road estimates were obtained from the GREET model which assumes less variation between test and on-road experience for FCEVs.

A.5 TOTAL FCEV SALES, STOCK AND HYDROGEN DEMAND

Regional estimates of FCEV sales, stocks and energy use were summed to produce national totals. Since all regional estimates were developed separately for cars versus light trucks, national summaries are by vehicle type (car versus light truck) as well.

TABLE A1 On-Road Fuel Economy of FCEV and ICEV Cars and Light Trucks

	Car mpgge (mi/gasoline gal equivalent)		Light Truck mpgge (mi/gasoline gal equivalent)	
Model Year	Gasoline (E10) ICEV	FCEV	Gasoline (E10) ICEV	FCEV
2015	26.2	54.1	20.1	41.4
2020	30.9	61.4	22.6	44.5
2025	34.5	72.0	24.1	52.0
2030	36.5	79.7	24.9	54.8
2035	39.0	89.8	27.7	57.7
2050	43.1	99.8	30.0	64.3

Table A2 shows the resulting national estimates of FCEV market penetration, sales and stocks by 10-year interval between 2020 and 2050. Though following different trajectories for cars versus light trucks, overall market penetration reaches nearly 20% of combined new car and new light truck sales in 2050. Sales of FC cars are significantly greater than sales of FC light trucks, particularly in the early years of the Multi-Market Scenario, because (a) penetration curves for light trucks are somewhat delayed as compared with auto curves and (b) FC penetration is greater in regions where trucks capture relatively smaller shares of the overall LDV market (e.g., the ZEV/Eastern region). These shares translate to nearly 3.9 million sales of FCEVs (cars + light trucks) in 2050 and over 33 million FCEVs on the road in that year. Total H_2 demand reaches nearly 7 million metric tons by 2050.

TABLE A2 National FCEV Market Shares, Sales and Stocks by Vehicle Type

Year	*Car*	*Light Truck*	*Total LDV*
		Market Penetration (%)	
2020	0.2	0.02	0.1
2030	2.8	0.6	1.6
2040	12.6	5.3	8.5
2050	24.6	15.4	19.8
		Sales (000)	
2020	13.3	1.2	14.5
2030	253.8	54.1	307.9
2040	1,311.3	439.1	1,750.4
2050	2,637.6	1247.9	3,885.5
		Stocks (million)	
2020	0.04	-	0.04
2030	1.01	0.24	1.25
2040	8.06	2.46	10.52
2050	22.39	11.02	33.41

REFERENCES

Blackman, A.W. (1974) *The Market Dynamics of Technological Substitutions*, Technological Forecasting and Social Change, Vol 6:41-63.

Mansfield, E. (1961), *Technical Change and the Rate of Imitation*, Econometrica Vol. 29 pp 741-765.

Paul, R.A. (1979), *The Impact of Future Diesel Emissions on the Air Quality of Large Cities*, U.S. Environmental Protection Agency Report EPA-450/5-79-005, Research Triangle Park, NC.

Santini, D.J. (1989), Interactions among Transportation Fuel Substitution, Vehicle Quantity Growth, and National Economic Growth, Transportation Research Part A, 23(3): 183-207.

Stephens, T., A. Birkey and D. Gohlke, 2017a. Vehicle Technologies and Fuel Cell Technologies Office Research and Development Programs: Prospective Benefits Assessment Report for FY2018, ANL/ESD-17/22 Argonne National Laboratory, Argonne, IL, November.

U.S. Energy Information Administration (EIA), *Annual Energy Outlook 2016*, 2016. Accessed Sept. 2017 at https://www.eia.gov/outlooks/aeo/.

APPENDIX B: VEHICLE COST ESTIMATES

Vehicle efficiency and technology cost are critical inputs to estimate vehicle and fuel demand and consequent economic impacts. As with the GPRA effort, this study relied on the Autonomie model to provide those inputs. Developed by Argonne in collaboration with General Motors, Autonomie is a MATLAB©-based framework for automotive control-system design, simulation and analysis. Autonomie integrates a number of sub-models incorporating different processes and levels of detail (from subsystems to systems and entire architectures) to estimate performance, cost and other attributes of vehicles and key components. Several Autonomie powertrain models have been validated using Argonne's Advanced Powertrain Research Facility vehicle test data.

B.1 AUTONOMIE MODEL

Autonomie evaluates the fuel consumption and cost of a given vehicle architecture (ICEV, FCV, PHEV, etc.), by "building" a virtual vehicle of a given size using data for each component in the main Autonomie database. Internal algorithms are used to size vehicle components to meet the same vehicle technical specifications. Vehicle cost is then estimated from the cost of the individual components. Fuel economy is simulated for several different drive cycles. The assumptions used for the GPRA effort (and incorporated in this study) are documented in Moawad et al. (2017).

Autonomie forecasts attributes that are likely to be achieved in the laboratory in 2010 (reference), 2015, 2020, 2030 and 2045. Laboratory achievement is assumed to occur five years prior to market introduction. Thus, technology and cost points achieved for the 2010 laboratory year would be expected to appear in the market in 2015. For laboratory years 2015 and beyond low, medium and high progress levels are defined to capture uncertainties in component performance and cost. For this study we use Autonomic results for a high level of technology progress and low cost since these are assumed to correspond to the achievement of FCTO program goals (as also assumed in the GPRA analysis).

Autonomie models five powertrain configurations (ICEV, PHEV and FCEV, along with hybrids and battery electric vehicles), four ICE fuels (gasoline, diesel, E85 and CNG), and five vehicle classes (compact car, midsized car, small SUV, medium SUV and pickup truck). Vehicle components are sized through an iterative process to meet technical specifications for zero to 60 mph acceleration time, ability to maintain 65 mph speed on a 6% grade and 100 mph maximum speed. In addition to these specifications, FCEVs, are sized to permit a driving range of 320 miles with associated onboard hydrogen storage.

B.2 VEHICLE COST

Autonomie estimates of total vehicle manufacturing costs at volume by summing component costs and assembly costs (Moawad et al. 2017). All vehicle types are modeled using a constant set of performance parameters (acceleration time, top speed, gradeability, etc.). Technical progress, therefore, manifests itself as lower cost and/or improved fuel efficiency. For this study we used Autonomie results corresponding to a high rate of technology progress and low cost (i.e., a high rate of cost reduction). All costs are multiplied by a factor of 1.5 to estimate retail price equivalent (RPE) with a 50% markup.

APPENDIX C: MODELING EMPLOYMENT IMPACTS FROM MDS OF FCEVs

This appendix describes the methodology used to estimate the employment impacts of FCEV manufacturing, distribution, and sales (MDS). The FCEV market penetration and technology cost estimates described in Appendices A and B provided the input values used in the modeling described below.

Appendix C is divided into two sections. The first section provides an overview of the REMI PI+ model and how it is used to estimate the employment impacts of the expansion of FCEV markets. The second section describes the overall modeling process and how forecasts are used to generate economic impacts.

C.1 REMI PI+ AND THE USE OF INPUT-OUTPUT MODELING

Employment impacts are estimated using the REMI PI+ model developed by Regional Economic Models, Inc. REMI PI+ is a dynamic, multi-regional, software model which incorporates several different economic methodologies: Input-Output (IO), Computable General Equilibrium (CGE), New Economic Geography, and Econometrics.

PI+ is centered around an input-output table which models inter-industry dependencies in an economy. The model begins with a table that quantifies the value of purchases each industry makes from each other industry. Industries are both customers for and suppliers to one another, and they hire labor services from households in the form of employment. Households, governments and other industries make investments; foreign buyers also purchase the products of each industry. A change in production or demand for a particular industry causes that industry to change its purchases of inputs from each of its intermediate suppliers and its purchases of labor services from households. Those industries, in turn, must change their purchases from their suppliers, and so on through multiple rounds of spending that ripple through the economy. Changes in household income caused by increases or decreases in employment can also affect subsequent rounds of purchases.

REMI PI+ also incorporates aspects of Computable General Equilibrium, which involves balancing supply and demand along with long-run changes in prices, production, consumption, etc. and Economic Geography which captures effects of industry clustering and labor market access as they affect inter-regional trade, productivity, and competitiveness. The model provides advanced statistical techniques to represent elasticities, time-lags, and other effects.

For this project REMI PI+ was configured into 160 industries and five regions of the United States (Table C.1).

TABLE C.1 REMI Regions

Region	States
Western	CA; NV; OR; WA
Central Southern	AR; LA; OK; TX
ZEV/Eastern	CT; DC; DE; MA; MD; ME; NH; NJ; NY; PA; RI; VT
Central Industrial	IL; IN; KY; MI; OH; TN; WI
Rest of U.S.	AK; AL; AZ; CO; FL; GA; HI; IA; ID; KS; MN; MO; MS; MT; NC; ND; NE; NM; SC; SD; UT; VA; WV; WY

Data within REMI PI+ come from a variety of sources including the U.S. Department of Commerce's BEA, BLS and Census Bureau.[16] Forecasts are based on BLS industry forecasts and the Research Seminar in Quantitative Economics (RSQE) at the University of Michigan-Ann Arbor.[17] REMI PI+ comes shipped with two forecasts: a Standard National Control forecast and a Standard Regional Control forecast. Regional Control forecasts are generated from National Control forecasts.

Economic impact results are generated by comparing a forecast (with various user-specified changes) to a control forecast. The difference between the two represents the effect of the inputs. Figure C.1 illustrates this process.

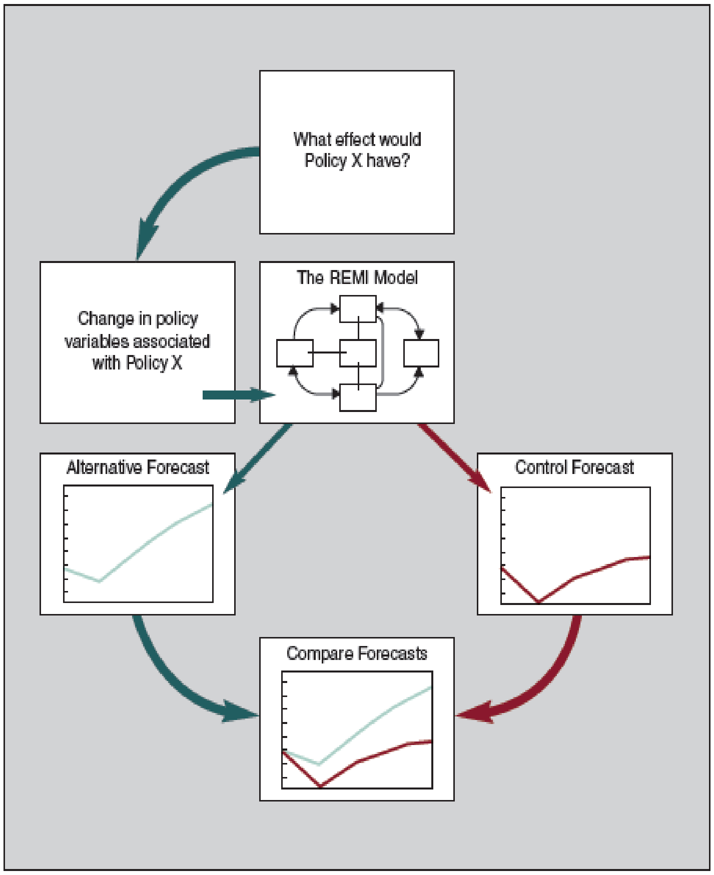

FIGURE C.1 REMI Model – Alternative vs. Control Forecasts[18]

[16] REMI PI+ 1.7 Data Sources and Estimation Procedures. 2015 Regional Economic Models, Inc. Accessed September 14, 2017. http://www.remi.com/resources/documentation

[17] REMI PI+ 1.7 Data Sources and Estimation Procedures. 2015 Regional Economic Models, Inc. Accessed September 14, 2017. http://www.remi.com/resources/documentation

[18] REMI Brochure. http://www.remi.com/wp-content/uploads/2017/03/2013-REMI-Brochure.pdf

C.2 APPLICATION OF REMI TO MODELING MDS OF FCEVs

REMI PI+ v1.7 was the economic model used to estimate employment impacts from the manufacture, distribution, and sale of FCEVs. The following discussion includes (1) the AEO 2016 update to the baseline forecast, (2) a description of the policy variables used to model the scenario, and (3) the custom industries developed for FCEVs.

C.2.1 Macroeconomic Update to REMI Baseline Forecast

For this project, a new National Control forecast was generated based upon the GDP data in the AEO 2016 Reference Case (EIA 2016). The VISION model (2016 release), which was used to estimate market penetration (described in Section 2.2), is calibrated to the vehicle sales forecasts in the AEO 2016 Reference Case. Thus, the underlying macroeconomic forecast in REMI was updated to reflect the AEO 2016 forecast.

REMI allows users to calibrate the control macroeconomic forecast by changing future estimates for six components of GDP. AEO 2016 provides a forecast for five of the six components for 2015 to 2040 (i.e., consumption, government spending, investment, imports, and exports). AEO 2016 does not provide an estimate for changes in Private Inventories. For this GDP component, the default value contained in REMI was used. After the national macroeconomic forecast was calibrated, the regional forecasts were updated based on the national. This updated Regional Control forecast was then utilized for all economic impact comparisons.

Table C.2 presents the results of the calibration. These estimates were used to update the REMI economic forecast through 2040. To extend the forecast to 2050, the AEO 2040 growth rate was carried forward. The end result was a REMI 2050 forecast of real GDP growth of 2.1% per year, and private non-farm employment growth of 0.8% per year. While both exports and imports grow, they do so in a way that produces a gradual decline (over time) in the U.S. trade deficit as a percent of real GDP. All of these assumptions are in line with the AEO 2016 forecast. This is summarized in Table C.2 below.

TABLE C.2 REMI Baseline Forecast Compound Annual Growth Rates (CAGR)

	EIA AEO 2016	Calibrated REMI Baseline Forecast	
Macroeconomic Indicator	2015 to 2040 CAGR	2015 to 2040 CAGR	2015 to 2050 CAGR
Real Gross Domestic Product	2.2%	2.1%	2.1%
Employment, Nonfarm	0.7%	0.7%	0.8%
Real Exports	4.3%	4.2%	3.6%
Real Imports	3.8%	3.6%	3.2%

C.2.2 Policy Variables in REMI PI+

REMI PI+ has several methods available to model changes to regional economics such as a change to industry output, a change in regional demand for goods and services, labor pool dynamics, adjustments to net exports, and several other factors. Within REMI, the methods are collectively called “Policy Variables”. A REMI Policy Variable can be thought of as a variable in a larger economic production function. To use a REMI Policy Variable, new values are specified for the item being modified, which the model then resolves with its internal system of equations and produces a new forecast of the economy (employment, output, etc.). Each REMI Policy Variable, therefore, links the values of new output or new demand to the regional and larger national economy through appropriate economic functions and standard relationships. Each user-specified forecast in REMI PI+v1.7 requires the user to identify specific REMI variables and industries, and then enter values by variable, industry, and region. This project utilized several different REMI Policy Variables including:

- Exogenous Final Demand – i.e., a change in total demand in the specified industry.

- Industry Sales/Exogenous Production – i.e., sales to exogenous non-export sources of demand (at the 4-digit NAICS level).

- Detailed Industry Sales/Exogenous Production – i.e., sales to exogenous non-export sources of demand (at the 6-digit NAICS level).

- Custom Industry Output/Sales – i.e. sales to exogenous non-export sources of demand (for a custom industry developed by analyst).

The Exogenous Production/Sales variables were used when an explicit assumption about the location of production was made. The Exogenous Final Demand variable was used when the demand for an industry in a region was known, but the location of production was not explicitly assumed. In such cases, the REMI model determines the location of supply.

Exogenous Final Demand and Industry Sales/Exogenous Production variables allow for the selection of industries from a typical 160 industry list which generally corresponds to the NAICS classification of industries at the 4-digit level. More specifically, detailed industries can be selected using the Detailed Industry Sales / Exogenous Production variable.C.2.3 Industries for FCEV Manufacturing.

C.2.3 Industries Associated with FCEV Manufacturing

Modeling FCEV manufacturing in REMI required examining the total value of FCEVs in terms of vehicle components and then selecting either an existing REMI industry or developing a custom industry to represent that component. The existing vehicle manufacturing industries found in REMI reflect conventional vehicles. Custom Industries were developed for components of FCEVs that are not comparable to conventional vehicle manufacturing (such as fuel cells). Further, since the FCEV was being broken down into several independently modeled components, additional custom industries were developed to avoid double-counting of vehicle components. Modeling each manufacturing activity separately has several benefits. First, it allows for more accurate industry customization as the adjustments can be made in several layers. Second, it allows for scenarios with different assumptions about production locations for one or more components. Third, the approach allows for scenarios in which the quantities of fuel cells and/or fuel cell stacks produced domestically differ from each other or from the quantities of FCEVs produced domestically or by region due to assumptions about exports, replacements, etc. In order to account for specific assumptions about intermediate inputs, the locations of activities and industry attributes relating to the manufacturing of FCEVs, FC systems, FC stacks, and other motor vehicle parts, each of these manufacturing activities was modeled independently. This required a series of steps to accurately represent these activities, avoid double-counting, and ensure consistency with the modeling of displaced conventional vehicles.

Estimated FCEV-related manufacturing costs were developed from both REMI and Autonomie data. Autonomie provided estimated manufacturing cost for all major components of an FCEV including the fuel cell, battery, transmission and hydrogen storage tank. Manufacturing costs for various FCEV-related manufacturing activities were developed according to the following steps. First, the total motor vehicle parts' costs for conventional vehicles were estimated by multiplying the motor vehicle parts' portion of total output (intermediate inputs, industry 3363, from REMI) by the conventional vehicle manufacturing cost (from Autonomie). Secondly, the sum of all other motor vehicle parts for conventional vehicles as identified in the Autonomie data, was subtracted from the calculated total motor vehicle parts' cost to yield motor vehicle parts' cost for the remainder of the vehicle. This remainder (for items like tires, brakes, the vehicle body or "glider", etc. which are common to both FCEVs and ICEVs), was then utilized in modeling FCEV-related manufacturing.

Therefore, FCEVs have several initial, general categories of costs:

- Total motor vehicle parts' costs:
  - Motor vehicle parts' costs identified by Autonomie for FCEVs
    - Fuel cell
    - Engine
    - Battery
    - Motor
    - Transmission
    - Fuel tank
  - Remainder motor vehicle parts' costs for FCEVs (described above)
- FCEV cost: balance of vehicle (FCEV manufacturing cost minus total motor vehicle parts' cost)

The REMI industry selected for each of the above categories is noted in Table C.3. Fuel cells were modeled independently as custom industries representing fuel cell systems (excluding the stack) and fuel cell stacks. Battery costs were included in industry 3359 ("other electrical equipment and component manufacturing") while costs associated with engines, motors, transmissions, and fuel tanks were grouped with other motor vehicle parts' and sent to "motor vehicle parts manufacturing” (industry 3363). For the FCEV (excluding motor vehicle parts), a custom industry was developed for cars and light trucks separately which is discussed below.

TABLE C.3 Industries Used for Modeling FCEV Manufacturing

Vehicle Component	REMI Industry
Custom Industries Developed for this Study	
FCEV Car (excluding motor vehicle parts)[1]	Custom Automobile Manufacturing (336111)
FCEV LT (excluding motor vehicle parts)	Custom Light Truck and Utility Vehicle Manufacturing (336112)
FC System (excluding stack)	Custom Other Miscellaneous Electrical Equipment and Component Manufacturing (335999)
FC Stack	Custom Other Miscellaneous Electrical Equipment and Component Manufacturing (335999)
Existing REMI Industries	
Batteries	Other electrical equipment and component manufacturing (3359)
Other Motor Vehicle Parts	Motor vehicle parts manufacturing (3363)

REMI PI+ allows users to create Custom Industries by choosing a Base Region, Base Year, Base Industry and Base Detailed Industry. Then, users adjust Value Added Components – Compensation Shares and Capital Shares, Labor Productivities, and Intermediate Demand Components, to reflect more specific industry information or to model an industry not included within the REMI model. The REMI Policy Variable associated with Custom Industries is Custom Industry Output/Sales.

As shown above in Table C.3, four general categories of custom industries were utilized for this analysis. Each custom industry was developed from an existing “base” industry in REMI. The base industry used is denoted in the custom industry name following the word ‘Customized’.

The attributes of each combination of base industry, region, and year change as the underlying forecast in PI+ evolves over time. As described in Section 2.2.6, cars and trucks are produced in several regions. Although it was impractical to develop a custom industry for each region/year/industry, custom FCEV manufacturing industries were developed for each combination of:

- Year (2015, 2020, 2025, 2030, 2035, 2040 and 2045)
- Vehicle type (car and light truck)

- Region (Central Industrial and Rest of U.S. for cars; Central Industrial, Rest of U.S., and Central Southern for light trucks)

FC system and FC stack manufacturing were modeled independently to better represent the attributes of each of these manufacturing activities. For FC system (excluding stack) and FC stack costs, a custom industry was developed for each combination of:

- Year (2015, 2020, 2025, 2030, 2035, 2040 and 2045)
- Region (Central Industrial, Rest of U.S., and Central Southern)

The primary feature of the FC Car (excluding parts) and FC Light Truck (excluding parts) custom industries was zeroing out Motor Vehicle Parts Manufacturing (3363) from Intermediate Demand. In doing so, it was assumed that the same amount of "direct" employment and compensation was required (on a dollar of output basis, in a given region-year) to manufacture an FCEV as a comparable conventional vehicle. Output/Sales were modeled independently, with adjustments to the Compensation share, Capital share, and Labor Productivity to accurately represent the amount of employment and compensation that would have occurred had the entire value of Output been input to motor vehicle parts. The new Compensation value was calculated by dividing the value of Output (excluding motor vehicle parts) by the original Compensation share. The new Labor Productivity value was calculated by multiplying the value of Output (excluding motor vehicle parts) by the original Labor Productivity. Intermediate Demands were also adjusted to represent the remaining (non-motor vehicle parts) industries. Motor vehicle parts, including batteries, were entered as independent demand variables.

For the FC system (excluding stack) and FC stack custom industries, several steps were required to yield the appropriate Compensation and Labor Productivity values. For Compensation, data from Strategic Analysis were used to update the Compensation share (James et al. 2017b). Because the Compensation share was adjusted, and the stack was modeled independently, Labor Productivity was also adjusted to accurately represent the amount of employment and compensation that would have occurred had the entire value of the fuel cell been input. For the FC Stack industry nothing was subtracted from Output but the Compensation share and Labor Productivity values were adjusted. One key assumption behind these steps was to have the Average Compensation Rate be the same between the base and custom industries. Intermediate Demand Component values were adjusted to best reflect the parts and materials specific to fuel cell and fuel cell stack manufacturing based in part on data from Strategic Analysis (James et al. 2017b).

C.2.3 Industries for FCEV Distribution and Sales

In addition to FCEV manufacturing, FCEV distribution and sales (i.e. FCEV non-manufacturing) were also modeled. Existing REMI industries were selected for FCEV distribution and sales. The portion of the final purchase price (or RPE as provided by Autonomie) attributable to the cost of transportation, wholesale, and retail sale at dealerships was allocated to appropriate REMI industries. The table below shows the existing REMI industries used for modeling FCEV distribution and sales.

TABLE C.4 Industries Used for Modeling FCEV Distribution and Sales

Forecast Category	REMI Industry
FCEV non-manufacturing	Rail transportation
FCEV non-manufacturing	Truck transportation
FCEV non-manufacturing	Wholesale trade
FCEV non-manufacturing	Motor vehicle and parts dealers (441000)

APPENDIX D: METHODOLOGY FOR ESTIMATING EMPLOYMENT IMPACTS

Appendix D presents the methodology used for calculating Gross Direct and Supply Chain employment from hydrogen fuel cell vehicle manufacturing, distribution, and sales that was presented in Section 3. The methods and terms are derived primarily from the REMI model which was presented and summarized in Appendix C. In the following sections below, Appendix D summarizes the following: (a) terms and definitions of REMI result categories, (b) the calculation of change in total sector employment using REMI forecast estimates, (c) the method used to develop estimates of change in employment at the occupational level.

D.1 GROSS DIRECT AND SUPPLY-CHAIN EMPLOYMENT

Gross Direct and Supply Chain Employment was estimated based on forecasts produced in REMI. A description of the employment data in REMI as well as a discussion on the types of impact categories available is presented in the following sections below.

D.1.1 REMI Employment Data

The primary national, state, and county data source for REMI PI+ is the Bureau of Economic Analysis (BEA) State Personal Income (SPI) and Local Area Personal Income (LAPI) series which is available for the nation and states. The series includes 94 industries for the national and state level data.[19] Employment in REMI is measured in terms of jobs and not in terms of the number of people employed. This means, a single person can hold multiple jobs and therefore all jobs held by the worker are counted. The BEA employment series for states and local areas estimates the number of jobs as full-time plus part-time which are treated with equal weight. Employees, sole proprietors, and active partners are counted in the jobs estimates. Jobs that are not included in the series are unpaid family workers and volunteers.[20]

D.1.2 REMI Employment Impact Categories

Total Employment in REMI is the sum of three employment categories below:

- Private Non-Farm Employment
- Government Employment
- Farm

[19] REMI PI+ 1.7 Data Sources and Estimation Procedures. 2015 Regional Economic Models, Inc. Accessed September 14, 2017. http://www.remi.com/resources/documentation

[20] REMI PI+ 1.7 Data Sources and Estimation Procedures. 2015 Regional Economic Models, Inc. Accessed September 14, 2017. http://www.remi.com/resources/documentation

The focus of employment estimates presented in Section 3 is primarily on Private Non-Farm Employment. The change in Private Non-Farm Employment is further broken down by sector and by impact type. The impact type is calculated based on the REMI Model's Input-Output matrix (IO) which presents intermediate inputs, labor, and capital as a percentage of total output for each REMI sector. The IO table serves to calculate the inter-industry relationship resulting from a change in output or demand of an industry. As one industry experiences an increase in demand or output, it will increase its own purchase of inputs and labor required to meet that increase in sales from other industries thereby triggering those industries to increase output and sales as well. This inter-industry relationship continues through the full supply chain within a regional economy until all inputs are satisfied. The result is an overall expansion in output, labor, and investment.

REMI organizes the types of employment impacts resulting from a change in the economy into nine impact categories. The sum of the nine categories is Total Private Non-Farm Employment. The different measures of impact that REMI presents are summarized in Table D.1.

TABLE D.1 REMI Impact Categories – Total Private Non-Farm Employment[21]

REMI Impact Category	REMI Definition
Exogenous Industry Sales Employment	Employment needed to satisfy the direct amount of Industry Sales entered by the user into REMI.
Exogenous Industry Demand Employment	Employment needed to satisfy the direct amount of Industry Demand entered by the user into REMI.
Intermediate Demand Employment	Employment impacts resulting from the purchase of intermediate goods; i.e. inputs to the production of final goods.
Local Consumption Demand Employment	Employment needed to satisfy demand for consumer goods.
Government Demand Employment	Employment needed to satisfy demand for goods and services by government expenditures.
Investment Activity Demand Employment	Employment needed to satisfy demand for capital goods.
Exports to Multi-regions Employment	Employment needed to satisfy demand for a region's goods and services from the other regions in the multi-area model.
Exports to Rest of Nation Employment	Employment needed to satisfy demand for a region's goods and services from areas in the rest-of-nation region.
Exports to Rest of World Employment	Employment needed to satisfy the demand for a region's goods and services from the rest of the world.

[21] REMI PI+ 1.7. Glossary. Accessed September 12, 2017. http://www.remi.com/resources/glossary.

D.1.3 Gross Impact Calculations

The employment impacts calculated and presented in Section 3 are based on four impact categories from REMI. From the above categories in Table D.1, the four that were used in employment calculations are presented in below in Table D.2.

In an effort to not overstate gross impacts at this stage of the analysis, only categories that capture direct and supply chain impacts were used in the calculation of Gross Employment Impacts. This is because these categories represent a measurable addition due hydrogen fuel cell related business activity. While the remainder of the employment categories also capture a change in employment to the economy, the overall direction of that change is arbitrary at this state of the analysis. Once displaced vehicles are included for the net impact analysis, all impact categories will be examined.

TABLE D.2 REMI Impact Categories Used in Calculating Gross Impacts

Impact Category	Gross Direct and Supply Chain Impacts
Exogenous Industry Sales Employment	Direct Jobs resulting from FCEV manufacturing, distribution and sale
Exogenous Industry Demand Employment	Direct Jobs resulting from FCEV manufacturing, distribution and sale
Intermediate Demand Employment	Supply Chain Jobs resulting from intermediate inputs required by FCEV manufacturing, distribution, and sale
Exports to Multiregions Employment	Supply Chain Jobs resulting from interregional purchases associated with FCEV manufacturing, distribution, and sale

D.2 IMPACTS BY OCCUPATION

Occupation level results presented in Section 3 were derived from REMI's occupation-by-industry matrix and the employment impact results discussed in Section A.4.2. The data and calculations of occupation level results are discussed in more detail in the following sections below.

D.2.1 REMI Occupation by Industry Data

Occupation data in REMI is based upon Bureau of Labor Statistics' (BLS) Employment Projections (EP) program's National Employment Matrix. The EP program develops information about the labor market for the nation as a whole for 10 years into the future.[22]

[22] Bureau of Labor Statistics. Employment Projections. Accessed September 12, 2017. http://www.bls.gov/emp/home.htm

The historical data in the EP program's National Employment Matrix combines employment data from several different sources. Data on industries comes primarily from the Current Employment Statistics (CES) program and also from the Quarterly Census of Employment and Wages (QCEW). This employment is distributed to occupations using staffing patterns from the Occupational Employment Statistics (OES) survey. [23] In addition, the matrix incorporates data for industries not covered by CES and OES – agriculture and private households – from the Current Population Survey (CPS), as well as employment data for self-employed and unpaid family workers. [24] In summary, the baseline data used to develop projections is comprised of the following series:

1. OES: Nonfarm wage and salary employment

2. CPS: Agricultural industry employment, self-employed workers, and workers in private households

3. CES and QCEW: Job counts by industry

REMI PI+ 1.7 employment by occupation data series is based upon the 2012-2022 National Employment Matrix as presented in the 2012-13 edition of the Occupational Outlook Handbook. The 2012-2022 EP data provided baseline values for 2012 and projected data for 2022. The rates of occupational change between 2012 and 2022 are calculated by REMI using linear interpolation then extended back historically at the same rate of change, and extended forward at one-half the rate of change. [25] The occupations covered in the data and ultimately REMI reflect the occupational classification used in the OES survey which is consistent with the 2012 Standard Occupational Classification (SOC) system.[26]

D.2.2 REMI Occupation by Industry Calculation

REMI provides regional occupation by industry matrices which evolve over time based on the Bureau of Labor Statistics' (BLS) Employment Projections (EP). Matrices were exported from REMI for 2025, 2035, and 2050 for each region. The occupation matrices were then converted into percentages of total industry employment by dividing each occupation within an industry by the total industry employment. These percentages were then multiplied by the industry level employment impacts.

[23] Bureau of Labor Statistics. Employment Projections. Accessed September 12, 2017. http://www.bls.gov/emp/home.htm

[24] Bureau of Labor Statistics. Employment Projections. Accessed September 12, 2017. http://www.bls.gov/emp/home.htm

[25] REMI PI+ 1.7 Data Sources and Estimation Procedures. 2015 Regional Economic Models, Inc. Accessed March 17, 2016. http://www.remi.com/resources/documentation

[26] REMI PI+ 1.7 Data Sources and Estimation Procedures. 2015 Regional Economic Models, Inc. Accessed March 17, 2016. http://www.remi.com/resources/documentation

As presented in Section 3, occupations-by-industry were calculated for Supply-Chain Jobs in FCEV Manufacturing and Non-Manufacturing. Separate forecasts were produced in REMI for FCEV Manufacturing and Non-Manufacturing (see Section XX for more discussion on this) and the employment impact results for these forecasts were exported from REMI for each region for use in the calculation of occupations.

For the FCEV Manufacturing scenario, the subset of occupations examined were for manufacturing industries only (NAICS 31 through NAICS 33). These industries were then multiplied by their corresponding occupation-by-industry vector to yield the occupations for each industry within NAICS 31 through NAICS 33. Finally, the industries were summed together and then sorted for the top manufacturing occupations.

For the Non-Manufacturing scenario (distribution and sales), the subset of occupations examined were for distribution, wholesale, and sales related industries only (NAICS 42 through 48). These industries were then multiplied by their corresponding occupation-by-industry vector to yield the occupations for each industry within Wholesale (NAICS 42), Retail (NAICS 44-45), and Transportation/Warehousing (NAICS 48-49). Finally, these industries were summed together and then sorted for the top distribution and sales occupations.

Energy Systems Division
9700 South Cass Avenue, Bldg. 362
Argonne, IL 60439-4854

www.anl.gov